# *1993*

# *ANNUAL REPORT*

# *RAPPORT ANNUEL*

# *1993*

**Submitted To:**

**The MEND Board of Directors**
**Toronto,** ***March 29, 1994***

**Soumis au :**

**Conseil d'administration NEDEM**
**Toronto,** ***le 29 mars 1994***

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**MEND/NEDEM**

*MINE ENVIRONMENT NEUTRAL DRAINAGE PROGRAM*

*PROGRAMME DE LA NEUTRALISATION DES EAUX DE DRAINAGE
DANS L'ENVIRONNEMENT MINIER*

**June 11, 2004**

**Mr. J. White
Chairman, MEND Board of Directors
Falconbridge Limited
Suite 1200
95 Wellington Street West
Toronto, Ontario
M5J 2V4**

**Dear Mr. White:**

**On behalf of the Management and Technical committees of MEND, I am pleased to submit to you the MEND Annual Report for 1993.**

**Copies have been sent to other Board members for their review before the Board meeting of March 29, 1994.**

**Yours truly,**

**I.J. Itzkovitch
Chairman
MEND Management committee**

## MEND PARTICIPANTS NEDEM

Association minière du Québec
Atomic Energy Control Board
Canada Centre for Mineral and Energy Technology
Natural Resources Canada
Environment Canada
Fisheries and Oceans
Indian and Northern Affairs Canada
BHP Minerals Limited
Brunswick Mining & Smelting
Cambior Inc.
Cape Breton Development Corporation
Cominco Limited
Denison Mines Limited
Echo Bay Mines Limited
Falconbridge Limited
Homestake Canada
Hudson Bay Mining and Smelting Company Limited
INCO Limited
Lac Minerals
Les Mines Selbaie
Les Ressources Aur Inc.
Minnova Ltd.
Noranda Minerals Inc.
Placer Dome Inc.
Rio Algom Limited
Teck Corporation
Westmin Resources Limited
The Mining Association of Canada
The Mining Association of British Columbia
The Mining Association of Ontario
British Columbia Ministry of Energy, Mines and Petroleum Resources
Manitoba Energy and Mines
N.B. Coal
New Brunswick Department of Natural Resources and Energy
Newfoundland Department of Mines and Energy
Nova Scotia and Labrador Department of Natural Resources
Ontario Ministry of Northern Development and Mines
Ontario Ministry of Environment
Ministère de l'Énergie et des Ressources du Québec
Centre de recherches minérales
Ministère de l'Environnement du Québec
Saskatchewan Environment and Resource Management

## Associate Participants Associés

École Polytechnique
European Commission
Geological Survey of Canada
National Mine Land Reclamation Centre
Norwegian Pollution Control Authority
Swedish National Environmental Protection Board
Australian Nuclear Science & Technology Organization

United States Bureau of Mines
University of British Columbia
University of Western Ontario
University of Waterloo
US Geological Survey
Laurentian University

March 1994

**(Mine Environment Neutral Drainage) is a co-operative research program sponsored, financed and administered by 3 partners; the Canadian mining industry, the Government of Canada and the Governments of the provinces of British Columbia, Manitoba, Ontario, Québec, New Brunswick, and more recently Saskatchewan, Nova Scotia and Newfoundland. The objectives of MEND are to:**

- **provide a comprehensive, scientific, technical and economic basis for the mining industry and government agencies, to predict with confidence the long term management requirements for reactive tailings and waste rock; and**
- **establish techniques that will enable the operation and closure of acid-generating tailings and waste rock disposal areas in a predictable, timely, affordable, and environmentally acceptable manner.**

**Six committees direct and manage the technical components of the program: Prediction; Prevention & Control; Treatment; Monitoring; Technology Transfer; and International Liaison. These committees have specific mandates to develop techniques that reduce the environmental impact and financial liabilities caused by acidic drainage. A Management committee is responsible for managing the overall program and a Board of Directors reviews and approves budgets and program direction. The MEND Secretariat coordinates the activities of the committees and their respective programs. Participation in MEND is on a volunteer basis. Committee members contribute their time and expertise without financial compensation from MEND.**

**MEND is a 9-year program, scheduled for completion in 1997. The research program was redefined and refocussed in 1992 and is outlined in the Revised**

**Research Plan, 1992. Included in this Plan, is a component on New Ideas and Innovation, to solicit, assess, and fund new ideas that will lead to breakthrough technologies in the prevention and control of acid mine drainage.**

(Neutralisation des Eaux de Drainage dans l'Environnement Minier) est un programme de recherche qui est parrainé, financé et administré conjointement par 3 partenaires; l'industrie miničre canadienne, le gouvernement fédéral et les gouvernements de la Colombie-Britannique, du Manitoba, de l'Ontario, du Québec, du Nouveau-Brunswick, et plus recemment de la Saskatchewan, de la Nouvelle-Écosse et de Terre Neuve. Les objectifs de NEDEM sont les suivants:

- établir les fondements scientifiques, techniques et économiques permettant ą l'industrie miničre et aux organismes gouvernementaux de prédire avec confiance les besoins ą long terme en matičre de gestion des résidus réactifs et des stériles, et

- mettre au point des techniques permettant l'exploitation et l'abandon, de maničre prévisible, économique opportune et acceptable pour l'environnement, des aires d'élimination de résidus miniers acides et des stériles.

Le programme est composé de 6 comités techniques: Prévision, Prévention et contrōle, Traitement, Surveillance, Transfert de la technologie et Liaison internationale. Ces comités ont des mandats spécifiques afin d'explorer les différentes voies permettant de réduire l'impact environnemental du drainage acide ainsi que l'engagement financier qu'il représente. Le comité de gestion est responsable de gérer le programme général et le conseil d'administration révisent et approuvent les budgets et la direction générale du programme. Le secrétariat NEDEM coordonne les comités techniques et leurs programmes respectifs. La participation au programme ce fait sur une base volontaire. Les membres des comités fournissent temps et expertise sans contribution financičre de la part de NEDEM

NEDEM est un programme de 9 ans qui devrait źtre complété en 1997. La direction du programme a été redéfinie en 1992. et est présenté dans le Plan de recherche révisé 1992. Dans le cadre du plan, le groupe de travail sur les nouvelles idées a poursuivi ses activités afin de soliciter, d'évaluer et de financer les idées nouvelles qui permettraient de faire avancer la recherche dans le domaine de la prévention et du contrōle du drainage minier acide.

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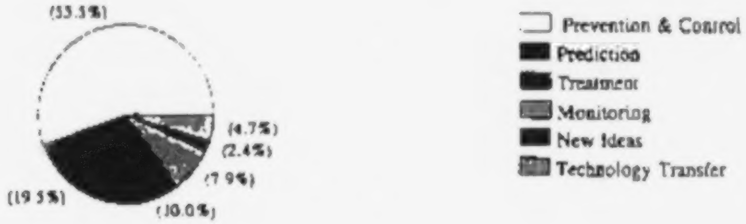
## TECHNICAL SUMMARY

The fifth completed year of the nine year program, 1993, was a watershed year for the MEND program. The Revised Research Plan approved by the Board of Directors in 1992 has been implemented. This has resulted in an increasingly focused program, pursuing those options considered economically and technically realistic. Low-cost technology is now available that allows new mines to open without acidic drainage being a major concern at closure. At operating and inactive mine sites, techniques are being confirmed that will significantly reduce closure costs. To ensure full implementation of these options within Canada, in 1993 the MEND program developed proactive Technology Transfer and Communications plans. A broader program base was also realized in 1993 through the participation of representatives from Fisheries and Oceans Canada, and the Provinces of Saskatchewan, Nova Scotia and Newfoundland.

The distribution of expenditures on Board approved projects is shown in Figure 1. Consistent with the program objectives, prevention and control of acidic drainage is the largest area of technology development and the research area with most potential to reduce the cost of acid mine drainage.

Figure 1. Expenditure by Technical Committee
Spent (1988 - 1993) & Committed (1994+)



In 1993, the Prediction Committee reconsidered the ambitious waste rock model development program that was proposed in 1992 and decided to proceed carefully on a step-by-step basis to produce a single waste rock modelling capability. Two of the steps taken were the establishment of a waste rock monitoring database and a review of the available geochemical models. The second phase of a major scientific study of geochemically active waste rock in Northwest Québec is nearing completion. This waste rock pile investigation has been the most comprehensive and innovative undertaken. The results provide the major advancement needed in the understanding of acid generation in waste rock piles. In 1994 additional emphasis will be placed in the area of chemical prediction and the assessment of predictive tests.

In Prevention and Control, research on underwater disposal and water covers continue to show very promising results. As recommended by a Peer Review in 1992, additional field work was undertaken in 1993 at lakes in Manitoba and British Columbia with the following results:

- ☐ the 1993 work confirms that the disposal of fresh, reactive sulphide tailings and waste rock under water prevents acid generation in the natural environment;
- ☐ unique world-class expertise in the field of high resolution water column measurement, and sediment sampling and analyses have been developed; and
- ☐ in 1994, this expertise will be transferred to others to monitor tailings deposited under water at a recently closed mine site in British Columbia and at a new mine in Québec to confirm the prevention of acid generation for the long term and at low cost.

Laboratory and field studies are continuing on the use of water covers, or wet barriers, over partially oxidized tailings and waste rock. As expected, submerged, oxidized mine waste can contaminate the water column but this contamination can be essentially eliminated by the use of inexpensive surface diffusion layers, and by the addition of surface alkalinity. In cases where the surface oxidation of tailings or rock is low, and where water covers can be established and assured for the long term, wet barriers are expected to have excellent low cost potential.

For over half of existing tailings sites and most waste rock sites in Canada, water covers are not an option. The use of dry, engineered, soil barriers has been extensively studied. Field results show a substantial (90 to 99%) reduction in water and oxygen penetration though the cover. Given the high cost of dry soil covers (\$15 to \$30/m$^2$), no further development work is planned. In 1993, a review of alternate dry cover candidate materials was undertaken. As a result:

- ☐ no further work will be done on cementitious covers;
- ☐ the Management committee recommends that only candidates that will substantially reduce the cost should be considered for further development work; and
- ☐ during 1994, the Prevention and Control committee will do economic analyses before recommending additional development on organic and modified soil covers.

Alternate prevention and control measures include the separation of sulphides from surface layers which may offer an economic solution for many tailings deposits. The Management committee directed that a review of existing cases of sulphide separation be done before undertaking extensive pilot tests. As well, field investigations at a thickened tailings discharge site in northern Ontario confirm that the water table is remaining high during operation, and that a depyritized or a fine tailings cover may be the most economical method of raising the water table upon closure.

In the mining industry, geophysical techniques have been primarily used for mineral exploration. In 1993, under the MEND Monitoring Committee, the application of geophysical monitoring techniques to acid mine drainage sites in the Sudbury area was successfully demonstrated. The use of such non-intrusive techniques in conjunction with more conventional methods will significantly reduce the costs associated with AMD site assessment and monitoring. Also initiated in 1993, was the preparation of an analytical standard to be used for static prediction testing of waste rock. Complete characterization of the material will be carried out in 1994 through a broad interlaboratory program.

The Treatment Committee recommended in 1993 that no further research and development be done on passive systems such as engineered wetlands. The results of laboratory and field work demonstrated that passive treatment has limited application in Canada, because of climate and low capacity restrictions. During the balance of the MEND program, the focus of this committee will shift to removal of metals prior to lime neutralization and to the stability of lime treatment sludges.

The New Ideas Task Force concluded its first year of reviewing, selecting and managing small proof-of-concept contracts that have potential for significant breakthrough technology, or that may lead to a significant improvement in existing technology. Of the 90 proposals received in late 1992 from the first solicitation, 13 proposals were provided with "seed" funding, of which 5 hold promise for success and are being supported further. At the end of 1993, 58 proposals were received and evaluated from the second solicitation. The Management committee has recommended that the Task Force conclude its work with the 1994 program.

To ensure the application of the advances developed by MEND, newsletters are being published, reports distributed and a proactive Communications plan developed for implementation in 1994 through the Technology Transfer Committee. Also in 1993, MEND related workshops were organized and presented by the provincial organizations in Quebec, Ontario and British Columbia . International interest in the results of the Canadian MEND program is increasing and the network of contacts in foreign countries continues to expand. In 1994, increased and substantive cooperation with international mining companies will be sought.

Finally, it is essential to recognize the volunteers from the Canadian mining industry and government organizations who contribute their expertise and time to MEND. Their input is vital in maintaining the scientific credibility of the program. The Management Committee commends these volunteers and their supporting organizations for their work, which has increased considerably as a result of the expanded accountability required by the Plan. In particular, the work by the chairmen of the technical committee, Dr. Henry Steger (Prediction), Mr. George Hope (Prevention and Control), Mr. Tom Hynes (Treatment), Mr. Ed Kustan (Monitoring) and Mr. Mike Sudbury (Technology Transfer) is recognised. To support the increasing activity within the program and financially supported by CANMET, the MEND Secretariat was expanded in 1993 from 2 to 3 technical coordinators as recommended by the Board of Directors. The Management committee was expanded in 1993 to include representatives from the Governments of Newfoundland, Labrador and Nova Scotia, Fisheries and Oceans Canada, and New Brunswick Coal.

## FINANCIAL REPORT

The financial commitment to MEND by its three partners, the Canadian Mining Industry, the Government of Canada, and the Provinces remained strong. Up to December 1993, $9.97 million had been spent on 107 MEND sponsored completed or active research projects and an additional $1.81 million committed as outlined in Table 1.

Tables 2 and 3 list the completed and active MEND projects as of the end of 1993. Table 4 lists projects which are submitted to the Board for approval. These projects will cost $2,310k, for which $1,415k has been committed by the funding partners. Table 5 compares the budget defined by the Revised Research Plan ($18,000k) per technical committee with the total funds expended and committed to MEND projects to date ($11,787k). It also summarizes the budgets associated with the projects proposed for initiation in 1994 ($2,310k) which would bring the total program commitments to $14,097k.

Table 1: Contributions to MEND 1988 to 1993 inclusive ($000's)

| | Spent (%) | Committed (Approved | Total (%) |
|---|---|---|---|

|  |  | Projects) |  |
|---|---|---|---|
| Mining Industry | 4,491 (45.0) | 342 | 4,833 (41.0) |
| Canada | 3,118 (31.3) | 984 | 4,102 ( 34.8) |
| Provinces | 2,365 (23.7) | 487 | 2,852 ( 24.2) |
| TOTALS | 9,974 (100.0) | 1,813 | 11,787 (100.0) |

As illustrated in Table 5, a majority of the technical committees have committed a high proportion of their budgets as defined in 1992 and for this reason the Management committee has directed all technical committees to review, and prioritize their programs during 1994, and to submit a revised budget for review in 1995.

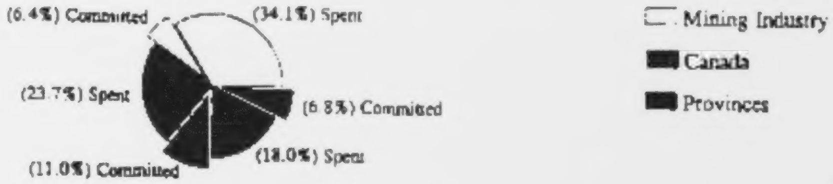
Mineral Development Agreements (MDA's), the primary source of federal funding through CANMET, are coming to an end in most provinces. MDA funds were allocated to MEND in New Brunswick, Québec, Ontario, Manitoba and British Columbia, and at this time a significant amount of federal funds (approximately $2.6 million) still remains uncommitted. For 1994, these agreements will be significant sources of MEND funding, and additional projects will need to be put into place before the later part of 1994. As these agreements are completed a wider federal participation in MEND will be needed to compliment the extensive participation by Natural Resources Canada through CANMET ($3.2 of $4.1 million).

Figure 2 shows the tripartite nature of the MEND program in terms of expenditures and commitments to date. Provincial funding for MEND improved in 1993, with significant funding from the Ontario Ministry of Northern Development and Mines, and from the provincial share of Mineral Development Agreements in Ontario and Québec. Similar to federal commitments, increased provincial commitments will be required since the balance of funding allocated to MEND in the provincial share of the MDA's will not meet the required share of $6 million of the $18 million program.

**As in past years, the overall funding commitment to the MEND program will remain an issue for the Board of Directors to address. The reality of the current economic climate in Canada must be balanced with the need to reduce potential long-term environmental liability to industry and governments.**

**I.J. Itzkovitch**

Figure 2: Expenditures by MEND Program Partners
Spent (1988 - 1993) & Committed (1994+)



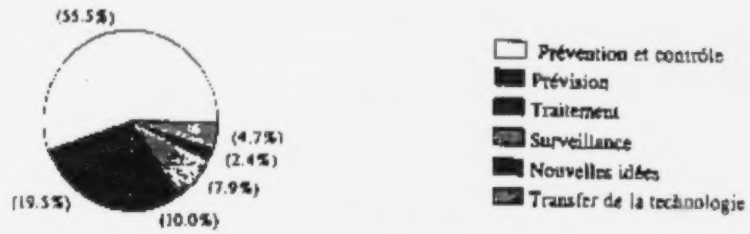
**Chairman**
**MEND Management Committee**
**March 21, 1994**

## RÉSUMÉ TECHNIQUE

La cinquičme année de mise en oeuvre du programme NEDEM, 1993, a été une année charničre pour ce programme. Le Plan de recherche révisé approuvé par le conseil d'administration en 1992 a été appliqué. L'orientation du programme a gagné en précision, se limitant aux objectifs économiquement et techniquement réalistes. Les nouvelles mines ont maintenant accčs ą une technologie peu coûteuse qui leur permettra de fermer sans que le drainage acide soit une préoccupation importante. Aux sites miniers qui sont actuellement exploités ou qui ne le sont plus, sont mises ą l'essai des techniques qui réduiront considérablement les coûts de fermeture. Pour assurer la mise en oeuvre complčte de ces techniques au Canada, en 1993, le programme du NEDEM a élaboré des plans proactifs de transfert de la technologie et de communication. Un élargissement du programme de base a été réalisé en 1993 avec la participation de représentants de Pźches et Océans Canada, et des provinces de la Saskatchewan, de la Nouvelle-Écosse et de Terre-Neuve.

La répartition des dépenses pour les projets approuvés par le conseil d'administration est présentée ą la figure 1. Conformément aux objectifs du programme, la prévention et le contrôle du drainage acide est le secteur de la recherche et du développement qui offre le plus de possibilités pour la réduction des coûts liés au drainage minier acide.

Figure 1. Contributions par comité technique
Dépensées (1988 - 1993) et sommes engagées (1994 -)



En 1993, le Comité de prévision a réexaminé l'ambitieux programme d'élaboration d'un modčle d'élimination des stériles qui avait été proposé en 1992, et il a décidé de procéder étape par étape pour acquérir la capacité d'élaborer un modčle unique des stériles. Deux des étapes ont consisté ą mettre sur pied une base de données de surveillance des stériles et ą analyser les modčles géochimiques disponibles. La deuxičme phase d'une importante étude scientifique sur des stériles géochimiquement actifs dans le nord-ouest du Québec est sur le point de se terminer. Cette étude sur les stériles a été la plus exhaustive et la plus innovatrice jamais entreprise. Les résultats obtenus ont permis de progresser dans la compréhension de l'acidification dans les haldes de stériles. En 1994, l'accent sera surtout mis sur la prévision des réactions chimiques et l'évaluation des essais de prévision.

Dans le domaine de la Prévention et contrōle, la recherche sur l'élimination subaquatique et l'utilisation de couvertures aqueuses continuent de donner des résultats trčs prometteurs. Comme il a été recommandé par une révision des pairs en 1992, des travaux additionnels ont été réalisés sur le terrain ą certains lacs du Manitoba et de la Colombie-Britannique. En voici les résultats:

☐ le travaux de 1993 confirment que l'élimination subaquatique des résidus et des stériles sulfurés réactifs non oxydés prévient l'acidification du milieu naturel;
☐ une expertise exceptionnelle de classe mondiale dans les domaines de mesure haute résolution dans la colonne d'eau ainsi que de l'échantillonnage et de l'analyse des sédiments a été acquise; et
☐ en 1994, cette expertise sera transférée ą d'autres pour la surveillance des résidus entreposés sous l'eau ą un site minier récemment fermé en Colombie-Britannique et ą une nouvelle mine au Québec, pour ainsi démontrer qu'il est possible de prévenir ą long terme et ą un coūt faible l'acidification des eaux de drainage.

Des études en laboratoire et sur le terrain se poursuivent sur l'utilisation de couvertures aqueuses ou de barričres humides sur les résidus et stériles partiellement oxydés. Tel que prévu, les déchets miniers oxydés submergés peuvent contaminer la colonne d'eau, mais cette contamination peut źtre essentiellement évitée par l'utilisation de couches de diffusion superficielles peu coūteuses et par l'augmentation de l'alcalinité en surface. Dans les cas ol l'oxydation en surface des résidus ou des stériles est faible et ol des couvertures aqueuses peuvent źtre mises en place et maintenues ą long terme, les couvertures humides offrent un excellent potentiel ą un coūt faible.

Pour plus de la moitié des parcs ą résidus et pour la plupart des haldes de stériles au Canada, les couvertures aqueuses ne constituent pas une option. L'utilisation de barričres sčches a été étudiée en profondeur. Les résultats sur le terrain indiquent une importante réduction (de 90 ą 99 %) de la pénétration d'eau et d'oxygčne ą travers la couverture. Étant donné le coūt élevé des barričres sčches (entre 15 et 30 $\$/m^2$), qucun projet de développement n'a été planifié. En 1993, on a entrepris une analyse des matériaux de remplacement utilisables dans les couvertures sčches. En voici les conclusions :

- ☐ les couvertures cimentées ne feront pas l'objet d'autres travaux;
- ☐ le Comité de gestion recommande que seuls les matériaux pouvant réduire considérablement les coûts fassent l'objet d'autres travaux de développement; et
- ☐ en 1994, le Comité de prévention et contrôle effectueront des analyses avant de recommander des travaux de développement supplémentaires sur les couvertures organiques ou de sol modifié.

Parmi les autres mesures de prévention et de contrôle, mentionnons la séparation des sulfures dans les couches superficielles, méthode qui peut constituer une solution économique dans de nombreuses décharges de résidus. Le Comité de gestion a demandé qu'une analyse des expériences actuelles de séparation des sulfures soit réalisée avant d'entreprendre des essais pilotes approfondis. De plus, des analyses faites ą un site d'entreposage de résidus épaissis dans le nord de l'Ontario confirment que la nappe phréatique demeure élevée durant l'opération et que le recours ą une couverture de résidus dépyritisés ou fins pourrait źtre la méthode la plus économique d'élever le niveau de la nappe phréatique ą la fermeture.

Dans l'industrie miničre, les techniques géophysiques sont surtout utilisées pour la prospection miničre. En 1993, dans le cadre du Comité de surveillance du NEDEM, l'application de techniques de surveillance géophysique aux sites de drainage minier acide dans la région de Sudbury a été démontrée avec succčs. L'utilisation de techniques non intrusives combinées avec des méthodes plus classiques permettront de réduire considérablement les coûts associés ą l'évaluation et ą la surveillance des sites de DMA. En 1993, une norme d'analyse ą utiliser dans les essais de prévision statique des stériles a en outre été élaborée. La caractérisation complčte du matériau sera réalisée en 1994 dans le cadre d'un vaste programme mis en oeuvre dans plusieurs laboratoires.

Le Comité de traitement a recommandé en 1993 de ne pas entreprendre d'autres travaux de recherche et de développement sur les systčmes passifs, comme les marécages artificiels. Les résultats obtenus en laboratoire et sur le terrain ont montré que le traitement passif a des applications limitées au Canada, ą cause du climat et de la faible capacité du procédé. Pendant la derničre partie de mise en oeuvre du programme NEDEM, ce comité mettra l'accent sur l'élimination des métaux avant la neutralisation par la chaux et sur la stabilité des boues traitées ą la chaux.

Le Groupe de travail sur les nouvelles idées a terminé sa premičre année d'analyse, de sélection et de gestion de petits contrats de preuve de concepts, qui offrent la possibilité d'effectuer une percée technologique importante ou qui pourraient permettre d'améliorer considérablement la technologie actuelle. Des 90 propositions reēues ą la fin de 1992 aprčs le premičre sollicitation, 13 ont reēu des fonds d'«amoreāge». Cinq d'entre elles présentent des possibilités de succčs et reēoivent, de ce fait, un appui supplémentaire. Ą la fin de 1993, 58 propositions ont été reēues et évaluées aprčs la deuxičme sollicitation. Le Comité de gestion a recommandé que le Groupe de travail termine ses travaux ą la fin du programme de 1994.

Pour s'assurer que les progrěs accomplis par le NEDEM seront mis en oeuvre, des bulletins d'information sont publiés, des rapports sont diffusés et un plan de communication proactif est élaboré et sera exécuté en 1994 par le Comité de transfert de la technologie. En 1993, des ateliers liés au NEDEM ont été également organisés et présentés par les organismes provinciaux du Québec, de l'Ontario et de la Colombie-Britannique. Les résultats du programme NEDEM canadien suscitent un intérźt accru dans le monde entier et le réseau des relations établies dans les pays étrangers continue de s'étendre. En 1994, l'objectif sera d'obtenir une collaboration accrue de la part des sociétés miničres internationales.

Enfin, il est essentiel de faire connaître les volontaires de l'industrie miničre canadienne et des organismes gouvernementaux qui offrent leur expertise et leur temps au NEDEM. Leur apport est vital ą la crédibilité scientifique du programme. Le Comité de gestion loue le travail de ces volontaires et de leur organisme d'appui, travail qui s'est accru considérablement par suite de la comptabilisation accrue exigée par le Plan. En particulier, le travail des présidents de comités techniques, Dr. Henry Steger (Prévisions), M. George Hope (Prévention et contrõle), M. Tom Hynes (Traitement), M. Ed Kustan (Surveillance) et M. Mike Sudbury (Transfert de la technologie) est reconnu. Pour appuyer les activités de plus en plus nombreuses entreprises au sein du programme et appuyées financičrement par CANMET, le nombre de coordonnateurs techniques du Secrétariat du NEDEM est passé de deux ą trois comme l'avait recommandé le Conseil d'administration. En 1993, le Comité de gestion a ajouté, au nombre de ses membres des représentants des gouvernements de Terre-Neuve et de la Nouvelle-Écosse, de Pźches et Océans Canada et de New Brunswick Coal.

## RAPPORT FINANCIER

La contribution financičre au NEDEM par ses trois partenaires qui sont l'industrie miničre canadienne, le Gouvernement du Canada et les provinces demeure élevée. En décembre 1993, 9,97 millions de dollars avaient été dépensés ą 107 projets de recherche complétés ou en cours, parrainés par le NEDEM, et une somme additionnelle de 1,81 millions de dollars avait été engagée (tableau 1).

Les tableaux 2 et 3 énumčrent les projets du NEDEM complétés et en cours d'exécution ą la fin de 1993. Le tableau 4 énumčre les projets présentés au conseil pour approbation. Ces projets coûteront 2 310 000 dollars, dont 1 415 000 ont été engagés par les partenaires financiers. Le tableau 5 compare le budget défini par le plan de recherche révisé (18 000 000 $) avec les fonds totaux dépensés et engagés dans les projets du NEDEM ą ce jour (11 787 000 $). Il résume également les budgets associés aux projets proposés pour 1994 (2 310 000 $), ce qui porterait les engagements totaux ą 14 097 000 $.

Tableau 1 : Contributions au NEDEM de 1988 ą 1993 inclusivement (en milliers de dollars)

| | Dépensées (%) | Engagées | Total (%) |
|---|---|---|---|

|  |  | (Projets approuvés) |  |
|---|---|---|---|
| Industrie miničre | 4 491 (45,0) | 342 | 4 833 (41,0) |
| Canada | 3 118 (31,3) | 984 | 4 102 (34.8) |
| Provinces | 2 365 (23,7) | 487 | 2 852 (24,2) |
| TOTAUX | 9 974 (100,0) | 1 813 | 11 787 (100,0) |

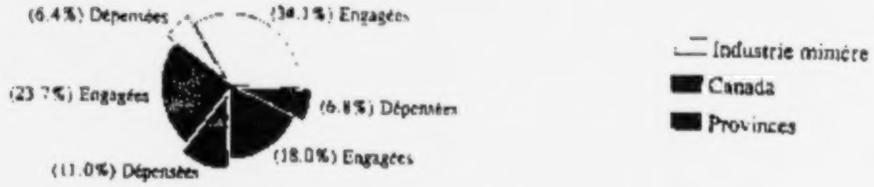
Tel qu'illustré au tableau 5, la majorité des comités techniques ont engagé une proportion élevée de leur budget, tel que défini dans le plan de 1992; pour cette raison, le Comité de gestion a demandé ą tous les comités techniques d'analyser et d'établir une échelle de priorité de leurs programmes en 1994 et de présenter un budget révisé pour analyse en 1995.

Les Ententes sur l'exploitation minérale (EEM), principale source de financement fédérale par l'intermédiaire de CANMET, sont sur le point d'expirer dans la plupart des provinces. Des fonds prévus dans les EEM ont été affectés ą des projets du NEDEM au Nouveau-Brunswick, au Québec, en Ontario, au Manitoba et en Colombie-Britannique, et, ą ce jour, des sommes importantes du gouvernement fédéral (environ 2,6 millions de dollars) n'ont pas encore été engagées. En 1994, ces ententes constitueront d'importantes sources de financement pour le NEDEM, et des projets supplémentaires devront źtre réalisés avant la derničre partie de 1994. Lorsque ces ententes seront expirées, la participation fédérale dans le NEDEM devra źtre accrue pour compléter la participation élevée de Ressources naturelles Canada par l'intermédiaire de CANMET (3,2 des 4,1 millions de dollars).

La figure 2 montre la nature tripartite du programme NEDEM en ce qui concerne les dépenses et les engagements faits ą ce jour. Le financement du NEDEM par les provinces s'est accrue en 1993, notamment par le ministčre de Développement du Nord et des Mines de l'Ontario et par la part provinciale des Ententes sur l'exploitation minérale en Ontario et au Québec. Les engagements par les gouvernements provinciaux devront, comme dans le cas des engagements du gouvernement fédéral, s'accroĭtre étant donné que le reste des fonds affectés au NEDEM dans la part provinciale prévue dans les EEM n'atteindra pas la part de 6 millions de dollars du programme de 18 millions de dollars.

**Comme durant les années passées, l'engagement financier global au programme NEDEM demeurera une question ą résoudre pour le conseil d'administration. La réalité du climat économique actuel au Canada devra źtre équilibrée par le besoin de réduire la responsabilité environnementale ą long terme qui pourrait incomber ą l'industrie et aux gouvernements.**

Figure 2: Contributions par les partenaires du NEDEM
Dépensées (1988 - 1993) et sommes engagées (1994+)



**I.J. Itzkovitch**
**Président**
**Comité de gestion du NEDEM**
**le 21 mars 1994**

## Table 2: Completed Projects

| Project | Title ($000's) | Budget ($000's) | Expenditures ($000's) | Variance ($000's) | Sponsors |
|---|---|---|---|---|---|
| 1.11.1 | AMD from Waste Rock - Literature Review | 50 | 50 | 0 | Env. Can. (25), Teck (25) |
| 1.12.1 | Compile AMD Prediction Data - Tailings & Waste Rock | 45 | 44.6 | 0.4 | B.C. (32.3), CANMET (12.3) |
| 1.14.1 | Field Evaluation Rock Hydrogeochemistry - Mine Doyon | 362 | 362 | 0 | Québec (94), Lac (134), Cambior (134) |
| 1.15.1 | AMD from Open Pits - Equity Silver | 55 | 53 | 2 | B.C. (10), CANMET (10), Placer Dome (33) |
| 1.16.1a | Evaluation of Prediction Techniques - Tailings & Waste Rock | 70 | 63 | 7 | CANMET (63) |
| 1.16.1b | Manual of Chemical Evaluation Procedures | 23 | 23 | 0 | CANMET (23) |
| 1.16.1c | Development of Static Evaluation Procedures | 40 | 21 | 19 | CANMET (21) |
| 1.17.1 | Hydrogeochemical Investigation - Waite Amulet | 235 | 285 | (50) | CANMET (117), Noranda (168) |
| 1.19.1 | Kinetic Tests for Cinola Gold Project | 100 | 94.3 | 5.7 | Env.Can. (47), B.C. (25), City Res. (2.4), CANMET (20) |
| 1.21.1a | Evaluate RATAP.BMT Capabilities | 30 | 30 | 0 | CANMET (30) |
| 1.21.1b | Workshop of Modelling Techniques - Tailings | 70 | 73 | (3) | CANMET (63), Falconbridge (10) |
| 1.21.1c | Prepare RATAP Users Manual | 30 | 19 | 11 | Env. Can. (19) |
| 1.24.1 | Development of Preliminary Modelling of Seepage Quality from Acid-generating Waste Rock Dumps | 285 | 21 | 264 | DIAND (21) |
| 1.25.1a | Development of a Soil Flux Model to Design Tailings Covers | 49.5 | 55.8 | (6.3) | CANMET (56) |
| 1.26.1 | Development of Modelling Methodology for Prediction of Seepage from Acid-generating Waste Rock | 90 | 90 | 0 | Env. Can. (30), B.C. (60) |
| 1.31.1 | Fundamental Reaction Kinetics - SIMS | 95 | 98.6 | (3.6) | Echo Bay (5), DIAND (18), Ontario (53.5), INCO (21) |
| 1.32.1 | Prediction and Prevention of ARD - A Geological & Mineralogical Approach | 73 | 73 | 0 | Env. Can. (55), Teck (3), HBM&S (3), BHP (3), Placer Dome (3), Cominco (3), Homestake (3) |
| 1.41.1 | International Workshop on Waste Rock Modelling | 10 | 7.7 | 2.3 | CANMET (0.5), Noranda (0.8), Falconbridge (0.8), Québec (0.8), |
| 2.11.1a | Evaluation of Existing Underwater Disposal Sites | 210 | 220 | (10) | B.C. (50), CANMET (70), HBM&S (65), Env. Can. (35) |
| 2.11.1b | Evaluation of Existing Underwater Disposal Sites | 250 | 136 | 114 | B.C. (5), CANMET (5), HBM&S (50), Env. Can. (26), Placer Dome (50) |
| 2.11.1c | Evaluation of Existing Underwater Disposal Sites | 50 | 68 | (18) | Placer Dome (68) |
| 2.11.1d | Peer Review on the Subaqueous Disposal of Tailings | 45 | 34 | 11 | CANMET (32.4), Placer Dome (2) |
| 2.11.2a | Literature Review - Metal Toxicology | 16.3 | 16.3 | 0 | Placer Dome (16) |
| 2.14.1 | Establish Vegetative Wetlands Over Tailings | 100 | 30 | 70Falconbridge (25), CANMET (5) | |
| 2.21.1 | Engineered Dry Covers for Tailings | 230 | 216 | 14Env. Can. (61), CANMET (35), DSS (120) | |
| 2.21.2 | Engineered Dry Covers for Tailings - Noranda | 469 | 533 | (64)CANMET (161), Noranda (220), Québec (152) | |
| 2.22.1 | Assessment of Hardpan | 150 100.5 | 49.5 | Manitoba (101) | |
| 2.23.1 | Documentation of Disposal Methods - Tailings & Waste Rock | 75 | 75 | 0 B.C. (38), CANMET (37) | |
| 2.23.2ab | Thickened Tailings Disposal (TTD) Method | 148.7 | 155.7 (7) | Falconbridge (155.7) | |
| 2.24.1 | Vegetation Manual | 35 33.5 | 1.5 | CANMET (34) | |
| 2.31.1a | Dry Covers on Waste Rock - Heath Steele | 400 | 312 | 88BM&S (172), New Brunswick (140) | |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| 2.32.1 | Blending and Segregation of Waste Rock - Kutcho Creek | 140 | 140 | 0 | Sumac (110), B.C. (15), CANMET(15) |
| 2.32.2a | Co-disposal of Tailings and Waste Rock - Mines Selbaie | 96 | 96 | 0 | Québec (76), CANMET (20) |
| 2.33.1 | ARD Remediation Measures at Four Norwegian Mines | 38.5 | 38.5 | 0 | B.C. (19.3), Norway (19.3) |

Table 2: Completed Projects Continued...

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| 2.41.1a | Electrochemical Oxidation/Passivation of Sulphides | 60 | 60 | 0 | HBM&S (10), Lac (10), Noranda (5), CANMET (35) |
| 2.44.1 | Microbial Plugging | 100 | 100 | 0 | CANMET (60), INCO (10), Noranda (20), Teck (10) |
| 3.11.1a | Treatment of Acidic Seeps Using Wetland Ecology and Microbiology | 230 | 281 | (51) | INCO (166), CANMET (40), Denison (25) Env. Can. (50) |
| 3.11.1b | Treatment of Acidic Seeps Using Wetland Ecology and Microbiology | 250 | 273 | (23) | INCO (83), CANMET (90), Denison (30) Env. Can. (70) |
| 3.11.1c | Treatment of Acidic Seeps Using Wetland Ecology and Microbiology | 128 | 125 | 3 | Env. Can. (27), CANMET (27), Québec (30) INCO (25), Denison (16) |
| 3.11.1d | Treatment of Acidic Seeps Using Wetland Ecology and Microbiology | 80 | 80 | 0 | Env. Can. (20), CANMET (20), Québec (20), INCO (20) |
| 3.12.1a | Assessment of Existing Natural Wetlands | 40 | 40 | 0 | Env. Can. (40) |
| 3.12.2 | Evaluation of Panel Wetlands | 45 | 45 | 0 | CANMET (22.5), Ontario (22.5) |
| 3.13.1a | Treatment of Small Seeps | 90 | 90 | 0 | Noranda (60), CANMET (30) |
| 3.21.1a | Metals Recovery from Acid Mine Drainage | 25 | 25 | 0 | CANMET (10), Env. Can. (15) |
| 3.21.2a | Removal of Metals - Chemical | 100 | 90 | 10 | Noranda (90) |
| 4.1.1 | Field Methods Manual - Tailings | 20 | 29 | (9) | CANMET (29) |
| 4.2.1 | Decommissioning Criteria | 15 | 15 | 0 | Ontario (5), HBM&S (5), Homestake (5) |
| 4.3.1 | Standard Reference Materials - Tailings | 50 | 50 | 0 | CANMET (50) |
| 4.5.2 | Field Sampling QA/QC | 9.5 | 9.5 | 0 | Noranda (9.5) |
| 4.6.2 | Continuous Monitoring of AMD - Literature Review | 50 | 50 | 0 | Québec (47) |
| 4.7.1 | Optimum Sampling Frequence | 27 | 27 | 0 | B.C. (13.5), CANMET (13.5) |
| 4.7.2 | Biological Monitoring of Acid Mine Drainage | 21 | 21 | 0 | B.C. (10.5), CANMET (10.5) |
| 4.7.3 | Aquatic Invertebrate Monitoring | 136 | 136 | 0 | B.C. (75), CANMET (42), Env. Can. (4), Noranda (15) |
| 4.7.4 | Acid Mine Drainage Sediment Monitoring | 6.5 | 6.5 | 0 | B.C. (4), CANMET (2.5) |
| 4.7.5 | Ion Speciation | 35 | 35 | 0 | B.C. (6), CANMET (6), Noranda (23) |
| 4.7.6 | Paleolimnology Techniques | 16.5 | 16.5 | 0 | Noranda (16.5) |
| 4.8.1 | Monitoring of the Flooded Solbec Pit | 139 | 139 | 0 | CANMET (30), Québec (109) |
| 5.1.1a-c | Provincial Workshops | 56 | 29.3 | 26.7 | Ontario (9.3), Québec (20)) |
| 5.3.1 | Laurentian Database | 35 | 35 | 0 | Ontario (35) |
| 5.3.2 | Expand Databases at Laurentian & UBC | 40 | 12 | 28 | Ontario (12) |
| 5.4.1 | ARD Technical Guide - version française | 24 | 24 | 0 | Québec (24) |
| 5.5.1 | Preliminary MEND Research Plan | 25 | 25 | 0 | CANMET (25) |

|  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
| 5.6.1 | **Second International Conference on the Abatement of Acidic Drainage** | 127 | 127 | 0 | CANMET (30), Teck (8), Env. Can. (15), Cominco (5), Rio Algom (4), Falconbridge (4), Placer Dome (4), INCO (11), Noranda (20), Cambior (4), MITEC (7), HBM&S (3), Ontario (7), B.C. (3), MAC (2), Québec (10) |  |
|  | ---- ---- ---- |  |  |  |  |  |
|  | **Totals** | 6,146.5 | 5664.3 | 482.2 |  | 01/03/94 |

## Table 3: Active Projects

| Project | Title | Approved Budget ($000's) | Expenditures ($000's) | Variance ($000's) | Sponsors ($000's) |
|---|---|---|---|---|---|
| 1.14.2 | Monitoring & Modelling AMD from Waste Rock Mine Doyon Phase II | 450 | 350 | 100 | Lac (75), Cambior (75), Québec (150), CANMET (150) |
| 1.15.2 | AMD from Open Pits - Expansion & Verification of Model | 88 | 37.3 | 50.7 | CANMET (53), Noranda (20.06) BHP(14.6) |
| 1.22.1 | ANSTO Model at Heath Steele | 145 | 90 | 55 | N.B. (25), Noranda (65), CANMET (85) |
| 1.31.2 | Residual Weathering Production Waste Rock Dumps | 40 | 20 | 20 | B.C. (20), Placer Dome (10) |
| 1.32.2 | Pyrite Oxidation - Lithological & Mineralogical Factors | 40 | 8.45 | 31.55 | B.C. (20), Homestake (5.3) |
| 1.41.2 | ARD Waste Rock Monitoring Database | 22 | 7.6 | 14.4 | CANMET (22) |
| 1.42.1 | Critical Review of Geochemical Modelling | 60 | 0 | 60 | Ontario (30), CANMET (30) |
| 1.51.1 | Quantitative Analysis of Chemical & Biological Kinetics | 12 | 11.75 | .25 | Env. Can. (12) |
| 1.51.2 | Nonlinear Modelling for Chemical Kinetics for AMD | 30 | 34.6 | (4.6) | Env. Can. (34.6) |
| 2.11.3ab | Evaluation of Underwater Disposal Sites - Anderson Lake | 400 | 235 | 165 | HBM&S (214), CANMET (180), Env. Can. (6) |
| 2.11.4a | Evaluation of Underwater Disposal Sites - Buttle Lake | 250 | 85 | 165 | HBM&S (214), CANMET (180), Env. Can. (6) |
| 2.13.1 | Flooding of Existing Tailings Sites - Quirke Lake | 835 | 835 | 0 | Rio Algom (502), CANMET (333) |
| 2.13.2 | Flooding of Existing Tailings Sites - Solbec Cupra | 260 | 262 | (2) | Cambior (90), CANMET (103), Québec (102) |
| 2.15.1 | Water Covers - Laboratory/ Field | 487 | 298 | 189 | Noranda (253), INCO (85), Lac (15), Ontario (30) |
| 2.20.1 | Evaluation of Alternate Dry Covers | 50 | 40 | 10 | CANMET (25), Ontario (25), Lac (5), DIAND (32) |
| 2.22.2 | Evaluation of Dry Covers Built from Mine Tailings | 235 | 160 | 75 | Québec (133), Ste-Genevičve (20), Lac (10), CANMET (107) |
| 2.23.2c | TTD - Tracer Study | 78 | 25 | 53 | Falconbridge (39), Ontario (20), CANMET (20) |
| 2.23.2d | TTD - Geochemical Study | 250 | 170 | 80 | Falconbridge (125), Ontario (60), CANMET (60) |
| 2.23.3 | Porous Envelope - Falconbridge | 123 | 140 | (17) | Falconbridge (70.2), Ontario (52.8) |
| 2.25.1 | Reclamation of Tailings using Municipal Solid Waste Compost | 130 | 76 | 54 | Falconbridge (53.5), Ontario (32.5) |
| 2.25.2 | Wood Waste Cover - East Sullivan | 431 | 177 | 254 | Québec (351) |
| 2.31.1b | Dry Covers on Waste Rock - Heath Steele | 368 | 298 | 70 | Noranda (121.3), N.B. (91.9), CANMET (154.5) |
| 2.32.3a | Tailings Injection - Literature Review | 10 | 10 | 0 | Québec (10) |
| 2.34.1 | Cementitious Cover - Westmin | 130 | 130 | 0 | Westmin (100), CANMET (30) |
| 2.35.2 | Lysimeter Covers for Waste Rock | 195 | 199 | (4) | Noranda (115), Québec (84) |
| 2.42.1a | Synthetic Polymers | 83 | 35 | 48 | INCO (22.5), Ontario (22.5) |
| 2.45.1a | Separation of Sulphides - Laboratory | 75 | 35 | 40 | Ontario (20), CANMET (20), Lac (15), Placer Dome (10) Mines Selbaie (10) |
| 3.21.1b | Removal of Metals - Ion Exchange | 64 | 17 | 47 | Teck (10), Falconbridge (4), Ontario (30), Homestake (20) |
| 3.22.1 | AMD - Water Quality Survey | 15 | 0 | 15 | Ontario (15) |
| 3.31 | Use of Lime Sludges for Capping | 30 | 12 | 18 | INCO (6.7), CANMET (23.3) |

Table 3: Active Projects Continued...

| | | | | | |
|---|---|---|---|---|---|
| 3.32.1 | Lime Treatment/ Sludge Stabilization | 60 | 38 | 22CANMET (30), Ontario (30) | |
| 4.3.2 | NNP Reference Material | 28 | 27.5 | .5 | Env. Can (26) CANMET (2) |
| 4.5.1 | Field Methods Manual for Waste Rock (Phase I & II) | 80 | 24 | 56 | CANMET (24), AECB (10), INCO (25), Homestake (10), Env. Can. (10) |
| 4.5.3 | ARD Technical Guide Revision - Monitoring Section | 50 | 33.7 | 16.3 | CANMET (50) |
| 4.6.1 | Geophysical Monitoring Methods | 118 | 130.6 | (12.6) | CANMET (38), Ontario (38), INCO (54.5) |
| 4.6.3 | Remote Monitoring - Techniques Review & Manual | 60 | 9.8 | 50.2 | Ontario (30), CANMET (30) |
| 4.6.4 | Piezocone Field Test | 26.7 | 12 | 14.7 | Ontario (17.6) INCO (9) |
| 4.8.2 | Sediment Sampling Probe Field Application | 51 | 19.6 | 31.4 | CANMET (17), Ontario (17), INCO (5), Falconbridge (12) |
| 5.2.1a-c | Communications Plan - CIMM Lectures, Brochure, TV Series | | 5 | 0 | 5CANMET (5) |
| 5.6.2 | Third International Conference on Abatement of Acidic Drainage | 15 | 12 | 3 | Ontario (5), CANMET (3), AMQ (4) |
| 5.7.1 | MEND Newsletter | 3 | 3.5 | (0.5) | CANMET (3.5) |
| 5.8.1 | Economic Evaluation of MEND-developed Technology | 40 | 0 | 40 | Ontario (40) |
| 6.1 | New Ideas - Round One | 162 | 200 | (38) | Teck (20), HBM&S (15), Lac (10), AMMQ (10), INCO (10), Ontario (20), CANMET (30), Québec (20), Noranda (55), DIAND (10) |
| | Totals | | | | 6084.7<br>4309.4<br>1,775.3<br>01/03/94 |

## Table 4: Projects Recommended for Board Approval

| Project | Title | Proposed Budget ($000's) | Funds Required ($000's) | Commitments/Comments ($000's) |
|---|---|---|---|---|
| 1.12.1b | DBARD - Continuation | 40 | 0 | B.C. (20), CANMET (20) |
| 1.13.1 | Climatic Controls - Review | 50 | 50 | |
| 1.14.3 | Mine Doyon - A Comprehensive Review | 40 | 0 | CANMET (20), Québec (20) |
| 1.16.2 | Inter Laboratory Program for NBM-1 | 20 | 0 | CANMET (10), Env. Can. (10) |
| 1.19.2 | Evaluation of Scaling (Bench, Pilot, Field) | 21 | 0 | Env. Can. (21) |
| 1.21.2 | Pyrrhotite Oxidation | 100 | 0 | CANMET (50), Ontario (50) |
| 2.11.5 | Shallow Water Covers - Equity Silver | 80 | 0 | Placer Dome (40), CANMET (40) |
| 2.11.9 | Underwater Disposal Sites - Design Criteria | 50 | 50 | Placer Dome, HBM&S, CANMET probable |
| 2.12.1 | Man-made Lakes Disposal Sites - Louvicourt Project | 350 | 350 | Teck, Aur, Québec, CANMET probable |
| 2.13.2b | Monitoring of the Flooding Solbec Cupra Tailings Site | 150 | 150 | Cambior, Québec probable |
| 2.13.3 | Flooding of Existing Tailings Sites - Falconbridge | 170 | 0 | Falconbridge (155), Ontario (15) |
| 2.21.3 | Peer Review of Waite Amulet and Heath Steele Soil Covers | 50 | 50 | |
| 2.21.4 | Protocols for Engineered Soil Covers over Tailings and Waste Rock | 30 | 30 | |
| 2.23.3 | Porous Envelope - Falconbridge (increase in scope) | 67 | 0 | Falconbridge (37), Ontario (30) |
| 2.35.2 | Lysimeter Covers for Waste Rock (increase in scope) | 80 | 40 | Noranda (40) |
| 2.36.1 | In-Pit Disposal - Case Studies | 50 | 50 | HBM&S probable |
| 2.36.2 | In-pit Underwater Disposal of Oxidized Waste RocK | 166 | 0 | Heath Steele (34), Noranda (132) |
| 2.45.2 | Separation of Sulphides - Case Studies | 50 | 50 | |
| 3.14.1 | Review of Passive Systems for Treatment of AMD | 60 | 0 | CANMET (60) |
| 3.21.3 | Removal of Metals - Pilot Tests | 125 | 125 | Go/No Go after evaluation of laboratory data |
| 3.41.1a | In Situ Treatment of AMD | 41 | 0 | MOE (30), Falconbridge (11) |
| 4.6.1b | Geophysics - Recommended Site Application | 100 | 0 | CANMET (50), Ontario (50) |
| 5.2.1d | Communications Plan - Video | 150 | 0 | CANMET (75), Ontario (75) |
| 5.4.2 | AMD Handbook | 150 | 0 | CANMET (75), Ontario (75) |
| 5.6.3 | Fourth International Conference on Abatement of Acidic Drainage | TBD | TBD | |
| 6.2 | New Ideas - Round Two | 120 | 0 | CANMET (15), Québec (20), Noranda (55), Env. Can (10), Ontario (20) |
| | Totals | | | |

## Table 5: 1994 MEND Program and Budget

|  |  |  | - Approved - |  |  | - Proposed - |
|---|---|---|---|---|---|---|
| Committee Area | Program ($000's) | Research Plan ($000's) | Budget: Revised Spent & Committed ($000's) | Proposed 1994 ($000's) | Committed 1994 ($000's) | Needed ($000's) |
| Prediction | Chemical Prediction | 1,314 | 995.9 | 131 | 81 | 50 |
|  | Modelling | 2,501 | 1,053.8 | 140 | 140 | 0 |
|  | Basic Research | 388 | 301.3 | 0 | 0 | 0 |
|  | SUB-TOTAL | **4,203** | **2351** | **271** | **221** | **50** |
| Prevention & Control | Underwater Disposal | 1,393 | 1,124.3 | 480 | 80 | 400 |
|  | Wet Barriers | 1,955 | 1,612 | 320 | 170 | 150 |
|  | Dry Barriers | 2,673 | 1,804 | 80 | 0 | 80 |
|  | Waste Rock | 2,110 | 1,289.5 | 296 | 206 | 90 |
|  | Other | 1,150 | 924.7 | 117 | 67 | 50 |
|  | SUB-TOTAL | **9,281** | **6,754.5** | **1,293** | **523** | **770** |
| Treatment |  | **1,729** | **1,218** | **226** | **101** | **125** |
| Monitoring |  | **1,125** | **948.2** | **100** | **100** | **0** |
| Technology Transfer |  | **362** | **315.3** | **300** | **300** |  |
| New Ideas & Innovation |  | **1,300** | **200** | **120** | **120** | **0** |
| **TOTALS** |  | **18,000** | **11,787** | **2,310** | **1,365** | **945** |

## 1.0 Introduction

Research being pursued by the Prediction Committee can be separated into three main areas: chemical prediction, predictive modelling, and fundamental research. The first two areas were within the original mandate of the committee, while the third area was included at the recommendation of the Management Committee in late 1991.

### 1.1 Chemical Prediction

Two projects were completed in 1993 which involved both static and kinetic predictive tests. Firstly, the preliminary DataBase for Acid Rock Drainage (DBARD) was successfully transferred to the University of British Columbia and over the past year static and kinetic test results from nearly 120 mines have been added. Continuation of data input and software improvement has been recommended for an additional year during which time decisions will be made regarding further development and long-term maintenance of the database. Secondly, the completion of the Cinola Gold project wraps up over five years of laboratory and field test plot studies. The data indicate a limited variation in oxidation kinetics between laboratory to the field. Project 1.23.1, Compilation of Rules is not expected to be completed, and has been removed from the program.

There are four projects recommended for initiation in 1994, which include the extension of DBARD, noted above. An assessment of the climatic effects of acid generation and metal leaching and their associated prediction is recommended through a review of the literature and available field and laboratory data. Also recommended is the interlaboratory test program for characterization of the standard material NBM-1. Assessment of sulphide and carbonate content of the material will be reported as will its net neutralization potential as defined by static testing. Finally, following on the Cinola Gold project (1.19.1), an assessment of bench to field test scale-up will be made.

Table 6: Chemical Prediction

| Complete | | Budget($) |
|---|---|---|
| 1.11.1 | AMD From Waste Rock - Literature Review | 50k |
| 1.12.1a | Compile AMD Prediction Data (DBARD) | 45k |
| 1.14.1 | Field Evaluation Rock Hydrochemistry - Mine Doyon | 362k |
| 1.15.1a | AMD From Open Pits - Equity Silver | 53k |
| 1.16.1a | Evaluation of Predictive Techniques | 63k |
| 1.16.1b | Manual of Chemical Evaluation Procedures | 23k |
| 1.16.1c | Development of Static Evaluation Procedures | 21k |
| 1.17.1 | Hydrogeochemical Investigations - Waite Amulet 1985/90 | 285k |
| 1.19.1 | Kinetic Tests for Cinola Gold | 94k |
| **Recommended** | | |
| 1.12.1b | DBARD - Continuation | 40k |
| 1.13.1 | Climatic Controls - Review | 50k |
| 1.16.2 | Interlaboratory Program for Standard Material NBM-1 | 20k |
| 1.19.2 | Evaluation of Scaling - Bench, Pilot to Field Scale | 21k |
| **Associate** | | |
| | Interpretation of Kinetic Tests for Predicting the Quality of Mine Tailing Effluents. | |

## 1.2 Modelling

**The model SoilCover, developed at the University of Saskatchewan to compute moisture fluxes between tailings, cover systems and the atmosphere, has been completed and will be made available in 1994. The modelling component of the prediction program focused however almost entirely on waste rock. The project on development of a modelling methodology for seepage quality from waste rock is considered completed. As well, nearing completion are two site specific projects. At Heath Steele, the gas and heat transport model FIDHELM is being applied to two piles, while at Mine Doyon, the second phase of comprehensive dump characterization will be completed by the spring of 1994. Also ongoing is the information compilation on availability, type and quality of waste rock monitoring data at waste rock dumps across Canada and internationally.**

**More recently initiated was the further development, application, and verification of the empirical model MINEWALL. It has been applied at the Equity Silver, Island Copper, and the Noranda Bell mine open pits and is being made applicable to underground mine walls. Initiated, and to be completed in 1994 is the review of geochemical models involving identification and assessment of geochemical processes as well as geochemical models of potential applicability to acid mine drainage (AMD).**

**There are two projects recommended for initiation in 1994. The first is a comprehensive**

review of the monitoring and modelling work that has been completed to date at the South dump of Mine Doyon through projects 1.14.1 and 1.14.2. The second deals explicitly with tailings, and will address pyrrhotite oxidation through laboratory and field studies. The ß-Evaluation of the Tailings Model (project 1.21.1d) is not expected to be completed as originally defined, and has been removed from the program.

Table 7: Predictive Modelling

| **Complete** | | **Budget($)** |
|---|---|---|
| 1.21.1a | Evaluate RATAP.BMT2 Capabilities | 30k |
| 1.21.1b | Workshop on Modelling Techniques | 73k |
| 1.21.1c | Prepare RATAP User's Manual | 19k |
| 1.24.1 | Development of Preliminary Waste Rock Modelling | 21k |
| 1.25.1 | Soil Atmosphere Flux Model to Design Tailings Covers | 56k |
| 1.26.1 | Development of Modelling Methodology for Prediction of Seepage Quality from Acid-Generating Waste Rock | 90k |
| 1.41.1 | International Workshop on Waste Rock Modelling | 8k |
| **Active** | | |
| 1.14.2 | Mine Doyon Phase II - Monitoring & Modelling | 450k |
| 1.15.2 | AMD From Open Pits-Expansion/Verification of Model | 88k |
| 1.22.1 | ANSTO Model at Heath Steele | 145k |
| 1.41.2 | ARD Waste Rock Monitoring Database | 22k |
| 1.42.1 | Critical Review of Geochemical Modelling | 60k |
| **Recommended** | | |
| 1.14.3 | Mine Doyon - A Comprehensive Review | 40k |
| 1.21.2 | Pyrrhotite Oxidation - Laboratory & Modelling Studies | 100k |

## 1.3 Fundamental Research

Surface sensitive analyses such as Secondary Ion Mass Spectrometry (SIMS) have been used to analyze the weathering of pure pyrrhotite and arsenopyrite minerals. Although two additional surface techniques used appear promising, further research in this area is not being considered for 1994. The completed report on a geological and mineralogical approach to prediction is

**currently available. It stresses the need to involve field geologists in the assessment of ARD, early on and through every stage of mining.**

**Two independent projects were initiated in 1993 to address the potential for chaotic behaviour in the kinetics associated with acid generation. In neither the chemical nor biological kinetics studied, was chaotic behaviour concluded to be significant. Ongoing are two Masters Theses at the University of British Columbia, one addressing residual weathering products from a dump leach mine site, the other studying the effects of rock morphology and composition on pyrite weathering rates.**

**No projects have been recommended in the area of Fundamental Research and New Ideas for consideration in 1994.**

**Table 8: Fundamental Research and New Ideas**

| **Completed** | | **Budget($)** |
|---|---|---|
| 1.31.1 | Study of Weathering Employing SIMS | 98k |
| 1.32.1 | Geological & Mineralogical Approach to ARD Prediction | 73k |
| **Active** | | |
| 1.31.2 | Residual Weathering Products in Waste Rock Dumps | 40k |
| 1.32.2 | Pyrite Oxidation - Lithological & Mineralogical Approach | 40k |
| 1.51.1 | Quantitative Analysis of Chemical and Biological Kinetics | 12k |
| 1.51.2 | Nonlinear Modelling of Chemical Kinetics for AMD | 30k |

## 2.0 Introduction

The Prevention and Control (P&C) Committee is the largest committee of the six technical committees in MEND. It has the largest budget and is responsible for about half of the expenditure of the MEND program. Although all committees must keep abreast of new technology, this is especially true for the P&C committee. To manage many activities more effectively, the P&C committee has sub-divided its research programs into five main areas: underwater disposal, wet barriers, dry barriers, waste rock and others.

## 2.1 Underwater Disposal

Early in the MEND program, consensus had been developed that placing acid-generating materials underwater would prevent sulphide oxidation. Underwater disposal is defined as the placement of fresh, unoxidized tailings underwater.

A work plan was developed in 1989, which consisted of evaluating, for two year periods, four lakes where tailings had been placed in the past. A preliminary evaluation and geochemical assessment on the tailings interstitial water was completed (2.11.1ab) on three of the four lakes. The work on Benson Lake (2.11.1c) completed the fourth lake (Table 9).

In 1992, the major focus was the completion of a Peer Review (2.11.1d) that was recommended of the Board of Directors in 1991. This review and presentations made to regulatory agencies in October 1992 provided feedback on the technical merits of the use of subaqueous disposal. Information deficiencies were also documented. A planning team of technical and scientific experts met in January 1993 and outlined a program which incorporated the Peer Review recommendations.

The planning committee focused on field and analytical techniques to improve measurement of metal fluxes at the sediment/water interface, and selected two lakes for continuing the study: Buttle as a deep lake and Anderson as an active, relatively shallow lake. The group planned a program to clarify understanding of the reactivity of the substrate, and to study the seasonal variations. Improved techniques to estimate metal flux, involving use of small dialyses chambers, or peepers, were located at the water/tailings interface. The group also recommended that at least three locations would be sampled in each lake for each sampling campaign, and that duplicates of all cores and peepers would be required.

Approval of the budget to conduct the additional work was obtained from the Board of Directors in March. Three major campaigns were conducted in 1993 - two on Anderson Lake and one on Buttle Lake. Timing of the Anderson campaigns was critical in that the milling operation using the site, the only active underwater disposal site available for study, was to be shutdown in early 1994. A further post-production campaign is planned for late 1994. For Buttle, a fall 1993 study was conducted. Preliminary results from the 1993 programs from both lakes, particularly the high-resolution water column sampling, confirm the findings from earlier studies. Also in 1993, as recommended by the Peer Review, a literature review on metal toxicology was completed (2.11.2a).

Two underwater disposal projects are recommended by the committee. The first, the design and operating criteria for an application manual (2.11.9) for subaqueous disposal will commence in 1994 in parallel with ongoing field studies. The second is a case study of underwater disposal of tailings at Equity Silver (2.11.5). A systematic evaluation of key design variables at this recently closed mine site and a comparison to the design criteria will yield either a verification of appropriate criteria or more applicable criteria. This work will assist in the development of the manual.

It is perceived that there may be public resistance to using natural lakes for underwater disposal of waste. The opportunity exists, however, to develop man-made underwater disposal sites. In 1994, the Management committee recommends that a field monitoring and laboratory program be undertaken at the new Louvicourt project in northwest Québec This is a unique opportunity to obtain field baseline data from a man-made lake tailings impoundment prior to commencement of tailings deposition scheduled for July 1994 and during operation. This program area was identified as a Priority I in the Revised Plan.

Table 9: Underwater Disposal Projects

| Completed Projects | | Budget($) |
|---|---|---|
| 2.11.1a | Evaluation of Existing Underwater Disposal Sites - 1988/89 Program | 220k |
| 2.11.1b | Evaluation of Existing Underwater Disposal Sites - 1990 Program | 136k |
| 2.11.1c | Evaluation of Existing Underwater Disposal Sites - 1991/92 Program | 67k |
| 2.11.1d | Peer Review on the Subaqueous Disposal of Tailings | 34k |
| 2.11.2a | Literature Review Report: Metal Toxicology | 16k |
| **Active Projects** | | |
| 2.11.3ab | Evaluation of Underwater Disposal Site - Anderson Lake | 400k |
| 2.11.4a | Evaluation of Underwater Disposal Site - Buttle Lake | 250k |
| **Recommended for 1994** | | |
| 2.11.5 | Shallow Water Covers - Equity Silver | 80k |
| 2.11.9a | Underwater Disposal Sites - Design Criteria | 50k |
| 2.12.1 | Man-Made Lakes Disposal Sites - Louvicourt Project | 350k |
| **Associate Project** | | |
| | Study of Submarine Ocean Tailings Disposal | |

## 2.2 Wet Barriers

As distinct from underwater disposal, wet barriers refers to establishing water cover on oxidized tailings. As with underwater disposal, continued oxidation is considered minimal but the mobilization of the soluble salts becomes a major consideration.

The proposed closure plans for several Canadian tailings sites call for water covers. Monitoring of the 65 hectares experimental test site and the laboratory columns at Quirke Lake continued in 1993. Discussions are underway for the release of pertinent reports on the project. Research into the effects of flooding tailings continued at the Solbec Cupra sites in 1993. It was found that placing a layer of sand on top of the tailings would reduce the needed water cover depth from 1.34m to 0.7m and prevent resuspension of tailings. A study on the chemical and microbiological effects of flooding and a synopsis report summarizing all the data collected at the site since 1989 are due in early 1994. Cambior, the owner of the site, is planning on flooding the site in 1994, pending government approval, and the committee recommends that a monitoring program be put in place if flooding proceeds. The committee also recommends that the Falconbridge flooding project be promoted to full status from associate status. After review it was confirmed that the work did add to the knowledge base for establishing the suitability and effectiveness of water covers (Table 10).

Work continued on the laboratory and field test program to simulate the movement of total acidity and metal loadings from oxidation products under different flow regimes and to predict treatment requirements. Some preliminary results from the laboratory and field studies with the Mattabi tailings suggest that leaching of zinc from the tailings may occur for a long period of time after flooding with a simple water cover. In this case the treatment of surface and seepage water may be required for extended times. However, early results show that surface amendments at the tailings and water interface can be used with oxidized materials to control the metal dissolution into surface waters.

Table 10: Wet Barriers Projects

| Completed Project | | Budget($) |
|---|---|---|
| 2.14.1 | Establish Vegetative Wetlands Over Tailings | 30k |
| **Active Projects** | | |
| 2.13.1 | Flooding of Existing Tailings Sites - Quirke Lake | 835k |
| 2.13.2a | Flooding of Existing Tailings Sites - Solbec Cupra | 260k |
| 2.15.1 | A Study on Water Covers for the Decommissioning of Mine Waste Disposal Sites | 487k |
| **Recommended for 1994** | | |
| 2.13.2b | Monitoring of the Flooded Solbec Cupra Tailings Site | 150k |
| 2.13.3 | Flooding of Existing Tailings Sites - Falconbridge | 170k |
| **Associate Projects** | | |
| | Flooding of Existing Tailings Sites - Stekenjokk, Sweden | |

## 2.3 Dry Barriers

The use of dry barriers to prevent further oxidation and/or transportation of oxidation products, has been the subject of considerable investigation. The cover materials evaluated to date in laboratory and in companion field studies include composite clay/soil covers and plastic membranes (Waite Amulet). The aim of properly designed composite covers is to maintain a saturated layer which prevents the transfer of oxygen. It has been found that these covers also effectively limit water transport through the cover. Monitoring of acid fluxes at the Waite Amulet site suggested that the rate of acid production decreases with time. A reduction of 80% in the total annual infiltration was also obtained. The effect of freeze/thaw on the integrity of the compacted clay layer showed that freezing and thawing have not adversely affected the cover. Many recommendations for additional work were identified in the final report. The committee decided that rather than doing additional work, a peer review on the work to date should be completed and a recommendation for such a study is being made (2.21.3). If the peer review is favourable, a set of design and construction protocols for soil covers (2.21.4) for use by others will be prepared (Table 11).

A laboratory project started in 1992 is evaluating mine tailings as a cheap alternative material for covers. When clay or low permeability soils are not readily available at many sites, alternate materials such as tailings having somewhat similar properties may be substituted. The results confirm that sulphide-free fine tailings offer promising characteristics as cover materials. Two other projects are evaluating organic covers which may function to limit

**oxygen penetration but not water penetration. Laboratory research has shown that compost covers can establish the conditions necessary to stop and reverse the acid drainage process but some reductive dissolution of metals has also been noticed and is being further evaluated. The results of a one-metre wood waste cover demonstrate that the cover effectively blocks access of oxygen which could oxidize underlying sulphates, as shown by the fact that methane is generated within the cover.**

**While dry covers do reduce the penetration of oxygen and/or water into the tailings, they may be too expensive, too short term or the needed materials may not be locally available. In 1993 a study to prepare a ranking of the potential alternate cover materials that could be further considered was undertaken (2.20.1). The review has also brought to light several yet unresolved concerns such as: the long-term effectiveness of dry covers as oxygen barriers, the net impact on the rate of oxidation of reactive tailings, poor availability of dry cover material in some locations, prohibitive cover construction costs, and effluent quantity, and quality and its impact on the receiving environment. The potential materials given a high priority include natural soils, modified soils, desulphurized tailings, tailings slimes, wood waste, and paper mill sludge. The final draft report was received in December and is being evaluated. Laboratory and field test programs on priority materials may be proposed in the future.**

Table 11: Dry Barriers Projects

| Completed Projects | | Budget($) |
|---|---|---|
| 2.21.1 | Engineering Dry Covers for Tailings - Laboratory | 216k |
| 2.21.2 | Engineered Dry Covers for Tailings - Noranda | 533k |
| 2.22.1 | Assessment of Hardpan | 101k |
| 2.23.1 | Documentation of Disposal Methods - Tailings and Waste Rock | 75k |
| 2.24.1 | Vegetation Manual | 34k |
| **Active Projects** | | |
| 2.20.1 | Evaluation of Alternate Dry Covers for the Prevention of Acid Mine Drainage from Tailings | 50k |
| 2.22.2 | Evaluation of Dry Covers Built from Mine Tailings | 235k |
| 2.25.1 | Reclamation of Sulphide Tailings Using Municipal Solid Waste Compost | 130k |
| 2.25.2 | Design of an Organic Barrier Using Wood Waste - East Sullivan | 431k |
| **Recommended for 1994** | | |
| 2.21.3 | Peer Review of Waite Amulet and Heath Steele Soil Covers | 50k |
| 2.21.4 | Protocols for Engineered Dry Covers over Tailings and Waste Rock | 30k |
| **Associate Project** | | |
| | Engineered Dry Covers for Tailings - Curragh | |

## 2.4 Waste Rock

Although some of the cover techniques available for tailings may be applicable to waste rock, the circumstances and methods are different. Waste rock piles have the potential for developing induced air flows due to temperature gradients and porosity. Differential settlement in the piles may be greater with waste rock than tailings.

Monitoring of the Heath Steele composite clay/soil cover continued in 1993. Results indicate a reduction in gaseous oxygen concentration in the pile which implies reduced acid production. Temperatures in the pile have decreased following cover installation but appear to be more influenced by climatic variability. The quality of the seepage has not changed since cover installation in 1991. Monitoring will continue in 1994 to confirm the reduction in acid production, the level of stored acidity, and low percolation of water through the cover.

Through the New Ideas Task Force the P&C Committee was referred a project looking at the concept of the injection of tailings into a waste rock pile as a method to control AMD (Table 12). A literature review was completed and it revealed that the injection concept is a unique method that has not been tried before (2.32.3a).

Monitoring of the cementitious cover at Westmin has continued in 1993. Some superficial hairline cracks, formed during the curing period. Some cracks have penetrated through the cover and work is progressing to see how much moisture has reached the waste rock. A major consideration in the design of the testing program was cost and the transportation of aggregate to the mine was the largest cost. It was estimated that if local material was available, the unit cost per square metre could be less than twelve dollars, a saving of approximately 30 percent. The cover has stood up quite well and the committee suggests that a future project could involve the total encapsulation of a small waste rock pile to study whether the cementitious cover completely stops acidification.

The lysimeter study at Noranda Technology Centre evaluating several waste rock management techniques in specially-constructed lysimeters built for this purpose continued in 1993. The third year of monitoring has been completed and the most effective method of controlling acid generation was water cover, followed by limestone, soil cover, phosphate and wood bark. The monitoring will be completed in early 1994 and it is recommended that a project to look at the mineralogy, acid-base accounting and paste pH, and metal analyses of the effluents of the different lysimeters be carried out.

The committee also decided that no further work on blending and segregation be completed at this time. It was felt that better sampling and prediction protocols were necessary before continuing.

Approval is being requested to complete a case study review on the use of mined out pits as a depository for potentially acid generating materials. It is felt that this type of information if

**collected on all known sites, would be a very useful reference document for those in the mining industry contemplating the placement of waste rock in mined out pits. A second project involves a laboratory and field program to monitor the placement of oxidized material in a mined out pit at the Stratmat property (N-5 pit) in New Brunswick. This is a unique opportunity since baseline data are available.**

Table 12: Waste Rock Projects

| Completed Project | | Budget($) |
|---|---|---|
| 2.31.1a | Dry Covers on Waste Rock - Heath Steele | 312k |
| 2.32.1 | Blending and Segregation of Waste Rock - Kutcho Creek | 140k |
| 2.32.2a | Co-disposal of Tailings and Waste Rock - Mine Selbaie | 96k |
| 2.33.1 | ARD Remediation Measures at Four Norwegian Mines | 39k |
| **Active Projects** | | |
| 2.31.1b | Dry Covers on Waste Rock - Heath Steele | 368k |
| 2.32.3a | Injection of Mine Tailings into a Waste Rock Pile as a Method to Control AMD - Literature Review | 10k |
| 2.34.1 | Use of Cementitious Covers to Control Acid Generation at Westmin's HW Mine - Shotcrete Field Trial | 130k |
| 2.35.2 | Lysimeter Evaluations of Cover Alternatives - Noranda | 195k |
| 2.35.2 | Lysimeter Evaluations of Cover Alternatives - Noranda (increase in scope) | 83k |
| **Recommended for 1994** | | |
| 2.36.1 | In-Pit Disposal - Case Studies | 50k |
| 2.36.2 | In-pit Underwater Disposal of Oxidized Waste Rock | 166k |
| **Associate Projects** | | |
| | Instrumentation and Evaluation of the Mount Washington Reclamation Project | |
| | Segregation of Waste Rock at the Samatosum Mine | |

## 2.5 Others

This area covers the work that does not logically fit into the other four areas. A general area of research that is identifiable is pre-treatment. This includes chemical or physical treatment that could prevent acid generation in either the short or long term.

The concept of sulphide separation is being pursued by the committee as a pre-treatment option that could open up several economical disposal options if successful. The separation of sulphides project is evaluating various conventional mineral processing techniques that could be applied. Based on the results of the preliminary evaluation of four tailings samples, contained sulphides appear to be well liberated and therefore should be amenable to further treatment. An evaluation of each tested technique and recommendations of the most promising ones for future development will be included in the final report is due in March. From preliminary discussions with the contractor it is expected that flotation will be a recommended method for large scale pilot testing. Before completing large scale field testing of the recommended mineral processing techniques, the Management committee recommends the approval of a case study review on all known sites where sulphide separation was used at one time or another during their operations (Table 13).

Existing and new innovative tailings and waste rock disposal methods, in terms of their effectiveness in controlling acid production, is another area that is being investigated. Two projects on the examination and documentation of different types of tailings disposal methods were continued in 1993.

Results from the hydrogeological study of the thickened tailings discharge (TTD) method indicate that TTD is advantageous because of low dissolved metal fluxes to the environment. The tracer study has shown that the pore water velocities are slightly higher than predicted but compare well to those of clay materials. Monitoring of the tracers will continue for another year. The report from the geochemical study is due in 1994.

Electromagnetic surveys were used successfully at Falconbridge's porous surround project to identify the groundwater contamination plumes thus saving considerable cost in the installation of monitoring equipment. The measurement of hydraulic properties, hydrogeological analyses with numerical modelling and chemical monitoring of appropriate parameters existing on site are ongoing. It has been found that the tailings are mostly above the water table, except for the tailings located in the former kettle lake where a well defined water table was found. The model suggested that the contribution of tailings leachate to the regional groundwater system would be small. Greater depth to the water table, extra boreholes to locate the water table within the former kettle lake and additional monitoring wells because

**of seepage paths identified by the electromagnetic survey and the complex chemistry have resulted in the increase in scope being requested for approval.**

**Table 13: Others**

| | | Budget($) |
|---|---|---|
| **Completed Projects** | | |
| 2.41.1a | Electrochemical Oxidation/Passivation of Sulphides - Small Scale Scoping Studies | 60k |
| 2.23.2ab | Hydrogeological and Geochemical Analysis of TTD System at Kidd Creek | 149k |
| 2.44.1 | Microbial Plugging of Mine Tailings to Reduce the Production of AMD | 100k |
| **Active Projects** | | |
| 2.23.2c | A Tracer Study of Fluid and Contaminant Movement in the Upper Surface of the TTD System at Kidd Creek | 78k |
| 2.23.2d | Geochemical Evaluation of the TTD System at Kidd Creek | 250k |
| 2.23.3 | Porous Envelope Surround Disposal Method - Falconbridge | 123k |
| 2.42.1a | Development of Synthetic Polymers - Laurentian | 83k |
| 2.45.1a | Separation of Sulphides from Mill Tailings - Phase I | 75k |
| **Recommended for 1994** | | |
| 2.23.3 | Porous Envelope Surround Disposal Method - Falconbridge (increase in scope) | 67k |
| 2.45.2 | Separation of Sulphides from Mill Tailings - Case Studies | 50k |

## 3.0 Introduction

The Treatment Committee met in 1993 in Sudbury, Ontario, and Vancouver, B.C. to review active and new research projects, and to refine the treatment component of the Revised Research Plan.

There were four active projects at the end of 1993. One project on the recovery of metals from acid mine drainage, a review of lime treatment and sludge stabilization management practices, a survey on AMD characteristics, and a project on the polymerization of lime treatment sludge.

## 3.1 Wetlands and Treatment of Small Seeps

A 4-year project on the application of wetland ecology and microbiology (ARUM-engineered wetlands) was completed in 1993. Although good water quality was obtained, the capacity of the system was below original predictions. The final report provides details on the performance and applicability of the system.

The experimental work was completed on the mechanisms and performance of a natural wetland in treating acidic drainage at the Panel mine site in Elliot Lake. The results show that the wetland/water cover system is effectively treating acid from the partially submerged tailings.

The laboratory phase of the evaluation of passive systems for treatment of small seeps was completed. The systems tested were lime-organic mixture, anoxic limestone trenches, biotrenches and biosorbents. Because the performance at lower temperature (10°C), showed substantially poorer performance, the committee did not recommend a field test.

The Treatment committee has concluded that the use of passive systems to treat acidic seepages is technically feasible but the performance, costs and the applicability of these systems remain uncertain. Several process-limiting factors, such as temperature, flow rates, and rates of addition of bacteria nutrients, were identified during these studies. In order to summarize the results, MEND has decided to conduct a summary review of passive treatment systems for the Canadian environment in 1994.

## 3.2 Metals Removal From AMD

Two projects were conducted on the removal of metals from acidic drainage before lime neutralization. The first one is bench scale tests on selective precipitation which was completed in 1993, and the second is bench scale tests on ion exchange which will be completed in 1994. As outlined in the Revised Research Plan, either the ion exchange or the selective precipitation method would be tested on a small pilot scale. Based on the recommendations in the laboratory-scale studies, the selective precipitation technique will not be used for a pilot study.

**Pilot tests using ion exchange will be considered after completion of the laboratory study. If the decision is negative with respect to continuing the project for pilot scale tests, the budget resources will be switched to sludge and treatment products stabilization.**

## 3.3 Lime Treatment and Sludge Stabilization

**The major emphasis for the balance of the MEND Treatment program in this area will be the review of technology and production of a manual on lime treatment, and the determination of methods to stabilize treatment products. In 1993, a project to review of the state-of-the-art of lime treatment and sludge stabilization was initiated. A project was also initiated at Laurentian University to examine the use of modified sludges as a capping material for waste rock or tailings.**

Table 14: Treatment

| **Complete** | | **Budget($)** |
|---|---|---|
| 3.11.1a-d | Treatment of Acidic Seeps Employing Wetland Ecology and Microbiology - 1988-93 | 759k |
| 3.12.1a | Assessment of Existing Natural Wetlands Affected by Low pH, Metal Contaminated Seepages - 1990 | 40k |
| 3.12.2 | Evaluation of Wetlands at the Panel Dam "A" Site | 45k |
| 3.13.1a | Treatment of Small Seeps | 90k |
| 3.21.1a | Metals Recovery from Acid Mine Drainage | 25k |
| 3.21.2a | Metals Removal from Acid Mine Drainage - Chemical | 90k |
| **Active** | | |
| 3.21.1b | Metals Removal from Acid Mine Drainage - Ion Exchange | 64k |
| 3.22.1 | Survey of Acid Mine Drainage Characteristics | 15k |
| 3.31 | Use of Lime Sludges for Capping | 30k |
| 3.32.1 | Lime Treatment - Review and Sludge Stabilization | 60k |
| **Recommendations for 1994** | | |
| 3.14.1 | Review of Passive Systems for Treatment of AMD | 60k |
| 3.21.3 | Removal of Metals from AMD - Pilot Tests | 125k |
| 3.41.1a | In Situ Treatment of AMD | 41k |
| **Associate Projects** | | |
| | Field Evaluation of Acid Mine Water Treatment Using Constructed Wetlands at the Halifax Airport | |
| | Constructed Wetland at Noranda Bell Mine | |
| | Treatment of Acidic Seepage Using Chinese Alders | |

## 4.0 Introduction

In keeping with the priorities which were emphasized for 1993, the Monitoring Committee has focused, and will continue to focus, on a better understanding of standard sampling methods and the assessment and the development of new technologies for rapid, indirect monitoring of acid mine drainage sites.

## 4.1 1993 Activities

Projects completed in 1993 included an overview of regulations and guidelines pertinent to the decommissioning of AMD sites in Canada as well as selected in the United States with the main focus being on effluent quality. An international review of available continuous monitoring equipment potentially applicable to AMD sites was also commissioned. The review focused primarily on a limited number of integrated systems which measured specific physical and chemical parameters, but had not been applied specifically to AMD. As well, monitoring of effluent from the waste rock filled and flooded Solbec Pit in Québec has been terminated.

Nearing completion is an update of the monitoring chapter of the B.C. AMD Task Force Draft Technical Guide as well as two studies on specific field applications of monitoring techniques. A sediment probe has proven successful in identifying contaminated groundwater influx into surface water, while a resistivity piezocone appears to be applicable for the rapid characterization of soils and tailings.

A review of remote sensing and geophysical monitoring techniques applicable to AMD or potential AMD generating sites was initiated in 1993 and will be completed in early 1994. This work compliments the critical application and review of four geophysical processes recently completed. The comprehensive study successfully illustrated the applicability of electrical and electromagnetic surveys for economically monitoring subsurface AMD. Also initiated in late 1993 was the processing of the first standard (non ore-grade) material for Net Neutralization Potential (NNP). This reference material is expected to be instrumental in better defining quality control within and among laboratories doing static prediction tests.

## 4.2 1994 Program

Both the assessment of geophysical techniques and the recently initiated review of remote monitoring techniques generally are expected to point to areas for further development and application. These recommendations will be addressed specifically in 1994. Although geophysical techniques appear currently to be more applicable than remote sensing to the monitoring of AMD sites, both areas will be considered.

The development of a waste rock sampling manual, begun in 1993 will be finalized in 1994 with input from industry, regulators and consultants. The project output will include a

**recommended approach to waste rock sampling. It may also identify specific knowledge gaps which will be considered for further development.**

**Processing of additional material for development of a suite of standard reference materials, having varying mineralogy and NNP values will be considered under the prediction program, based on the usage and support shown for the first material.**

**Table 15: Monitoring**

| **Complete** | | **Budget($)** |
|---|---|---|
| 4.1.1 | Field Methods Manual - Tailings | 29k |
| 4.2.1 | Decommissioning Criteria | 15k |
| 4.3.1 | Standard Reference Materials - Tailings | 50k |
| 4.5.2 | Field Sampling QA/QC | 10k |
| 4.6.2 | Continuous Monitoring of AMD - Literature Review | 50k |
| 4.7.1 | Optimum Sampling Frequency | 27k |
| 4.7.2 | Biological Monitoring of AMD | 21k |
| 4.7.3 | Aquatic Invertebrate Monitoring | 136k |
| 4.7.4 | AMD Sediment Monitoring | 7k |
| 4.7.5 | Ion Speciation | 35k |
| 4.7.6 | Paleolimnology Techniques | 17k |
| 4.8.1 | Monitoring of the Flooded Solbec Pit | 139k |
| **Active** | | |
| 4.3.2 | Standard Material - Net Neutralization Potential | 28k |
| 4.5.1 | Field Methods Manual - Waste Rock | 80k |
| 4.5.3 | ARD Technical Guide Revision - Monitoring Section | 50k |
| 4.6.1 | Assessment of Geophysical Monitoring Methods | 118k |
| 4.6.3 | Remote Monitoring Techniques - Review | 60k |
| 4.6.4 | Piezocone Field Test | 27k |
| 4.8.2 | Sediment Sampling Probe Field Application | 51k |
| **Recommended for 1994** | | |
| 4.6.1b | Geophysical Monitoring: Further Application & Development | 100k |
| **Associate** | | |
| | Remote Sensing to Monitor Uranium Tailings Sites - AECB | |

## 5.0 Introduction

Technology Transfer is a significant and necessary activity for the MEND program. New initiatives were started in 1993 to increase information transfer to the users and to improve communications to targeted audiences.

## 5.1 Workshops/Conferences

During the fall of 1993 three workshops, organized by provincial MEND organizations, were held in Ontario, Québec and British Columbia. These technical sessions were well attended, demonstrating the strong interest an input in the control of AMD by industry and provincial government representatives. MEND also participated, as a co-sponsor with the United States Bureau of Mines, in the organization of the Third International Conference on Abatement of Acidic Drainage to be held in Pittsburgh, in April of 1994.

## 5.2 Communications/Publications

In addition to the publication of MEND reports, the MEND Newsletter is distributed to over 650 individuals and organizations to keep them informed on the current activities of MEND. Two issues of the Newsletter were published in 1993.

A communication expert was hired to aid in implementing the communications strategy proposed by the Communications Task Force appointed by the Board of Directors in 1992. Four communications vehicles were identified to inform key audiences about the issue of acidic drainage and the new affordable technologies being developed to solve the problem. The vehicles were the CIMM Distinguished Lectures Series, a print brochure to convey basic information about AMD and MEND, a series of television programs on the Mining Industry, and a video on AMD and MEND. The committee initiated the implementation of the communications plan and its activities will continue in 1994.

## 5.3 Databases

In 1993, the committee reviewed the functioning and usefulness of the Laurentian University Database, and provided financial support for its updating. The Database (Abandoned Mines, Acid Mine Drainage and Land Reclamation) contains over 9,000 abstracted references and is available on-line through INTERNET or through the purchase of diskettes.

Two databases are being developed at the University of British Columbia through the Prediction Committee. They focus specifically on the prediction of acid mine drainage and on data management. The DBARD (database for Acid Rock Drainage) project (1.12.1) will continue for an additional year while the Waste Rock Dump Monitoring Database project

**(1.41.2) will wrap up in early 1994.**

## 5.4 Economic Evaluation

**A scope of work was defined for a project to determine the base cost of prevention, control, and treatment of acid mine drainage with existing technology, and to develop a protocol for economic evaluation of existing and emerging technologies being developed by MEND. The project will start in March 1994.**

## 5.5 Intellectual Property

**In August 1992, the MEND Board of Directors decided that Arising Intellectual Property would be vested with the Crown, and a new policy was prepared. The Technology Transfer Committee continues to ensure that the new policy is implemented.**

Table 16: Technology Transfer

| **Complete** | | **Budget($)** |
|---|---|---|
| 5.1.1a-c | Provincial Workshops | 29k |
| 5.3.1 | Laurentian Database | 35k |
| 5.3.2 | Expand Databases at Laurentian & UBC | 12k |
| 5.4.1 | Acid Rock Drainage Technical Guide - version française | 24k |
| 5.5.1 | Preliminary MEND Research Plan | 25k |
| 5.6.1 | Second International Conference on the Abatement of Acidic Drainage | 127k |
| **Active** | | |
| 5.2.1a-c | Communications Plan - CIMM Lectures, Brochure, TV Series | 5k |
| 5.6.2 | Third International Conference on the Abatement of Acidic Drainage | 15k |
| 5.7.1 | MEND Newsletter | 3k |
| 5.8.1 | Economic Evaluation of MEND-developed Technology | 40k |
| **Recommended for 1994** | | |
| 5.2.1d | Communications Plan - Video on AMD/MEND | 150k |
| 5.4.2 | AMD Handbook | 150k |
| **Other Initiatives** | | |
| | Report Distribution by CANMET | |
| | Seminars, Workshops and Conference Presentations | |

## 6.0 Introduction

International interest in the MEND program continues to grow. This interest is shown in three ways: frequent and expanding requests for technical information on MEND results; questions about MEND as an industry-government cooperative effort; and how results are being applied.

International Liaison is not formalized into a committee, but is instead an informal network of contacts through the MEND Secretariat and technical committees

## 6.1 1993 Activities

The principle activity during 1993 was the exchange of written information and ideas with international mining companies and organizations. Several international mining companies visited the MEND Secretariat to discuss technology to prevent or treat acidic drainage. As has been the case in Canada, these companies have determined that acidic drainage, once initiated, is a long term treatment issue. Also, passive treatment systems such as engineered wetlands have not been proven to be widely cost or environmentally effective except for low acidity and dissolved metals cases.

Cooperation continues to be strong with agencies and individual scientists in many countries, particularly those in the United States and Australia. Twenty individuals from the United States, principally from the US Bureau of Mines, participate in MEND technical committees as full or associate members. Important technical developments in the United States in chemical predictive techniques, dry covers and passive water treatment systems are being closely monitored by MEND. Organizations such as ANSTO in Australia have contributed to the understanding of the fundamental principles of waste rock pile dynamics, and are transferring their science to Canada through work with MEND on the Heath Steele project, and other Canadian mining companies.

In 1993 international contacts expanded to include contacts in Japan, Finland, Russia, South Africa, China and several other countries in the far east. Official contacts have been established in the European Community and in several member states, in particular Germany where there are extensive acid-generating uranium and coal mine wastes.

MEND assisted the US Bureau of Mines and others in the preparation of the Third International Conference on Acidic Drainage, being held in Pittsburgh in April 1994. In addition to peer reviewing many of the papers being presented, MEND will be represented by 50 papers and posters.

## 6.2 1994 Program

**For 1994, international liaison is formalizing contacts for information exchange in several countries. The MEND Newsletter, which is currently mailed to over 300 international contacts will continue to be an important method of contact. International electronic data linkages, such as INTERNET, will be used for information exchange including abstracts of MEND reports. International mining companies will be the primary focus of the information exchange.**

## 7.0 Introduction

A New Ideas Task Force was approved by the MEND Board in August of 1992. The Task Force was set up to solicit and develop new ideas and innovation that could provide technology to significantly reduce the cost of preventing, controlling and treating acidic drainage. To date there have been two rounds of proposal solicitation.

## 7.1 Proposal Solicitation - Round 1

A simple and concise proposal format was developed and distributed Canada-wide in late 1992. Universities were targeted in the first Round. MEND members were canvassed for up-front seed funding. Ninety proposals were received and evaluated and eleven were accepted for funding, in addition to the two projects titled "Status of U.S. Research" and "Permafrost" that had been earlier initiated. Those proposals considered of technical merit but not necessarily a "new" idea were forwarded to the appropriate technical committees.

Table 17: New Ideas Projects - Round 1

| New Ideas # | Title | Proponent | Budget($) |
|---|---|---|---|
| 0 | Status of U.S. Research | Tarassoff | 6k |
| 01 | Permafrost to Prevent AMD | Geocon | 9k |
| 05 | Low Cost Wax Cover | CANMET | 10k |
| 15 | Chelating Ribbons | University of Manitoba | 10k |
| 17 | Chemically Modified Clay | Alberta Research Council | 10k |
| 28 | Artificial Hardpan | CANMET | 10k |
| 31 | Ion Exchange Resin | McGill University | 10k |
| 58 | Phosphate Coating | Université Laval | 10k |
| 65 | Sulphide Passivation | Technical U. of Nova Scotia | 5k |
| 69 | Comingling of wastes | UBC | 10k |
| 73 | Japanese Technology | Laurentian University | 10k |
| 83 | Chelating/Filtering of AMD | Zenon | 10k |
| 90 | Polymer Gel Cover | Université Laval | 10k |

[illegible]

## 7.2 Proposal Solicitation - Round 2

Based on the results of the first round of solicitation the Task Force initiated a second solicitation in late 1993. Between October and December 1993, the New Ideas Task Force solicited innovative ideas from across Canada, by advertising in the MEND Newsletter, CIMM bulletin and by doing presentations at several locations across Canada. By the end of the year, 58 proposals had been received and an initial evaluation showed that 7 proposals had merit for closer consideration by the Task Force. Also, 9 proposals appeared to be focussed on of areas of work under the defined program in the 1992 Revised Research Plan, and were referred to the technical committees for inclusion in their upcoming programs. Up to 13 projects will be funded in 1994, for an expenditure of $120,000.

## 7.3 Proposed Program for 1994

In January, 1994, the New Ideas Task Force evaluated the results to date, and made the following recommendations for the remaining years, 1994 to 1997, of the MEND program. The Task Force suggested that MEND:

- Discontinue annual solicitation, screening and contract management;
- Continue to screen and review unsolicited "new ideas" proposals;
- Recommend where appropriate brainstorming, questionnaires, interviews; and
- Implement new ideas projects by technical committees with "champions."

The New Ideas Task Force will ensure the completion and publication of work initiated in the first and second rounds of proposal solicitation. The long-term role of the Task Force will be finalized in early 1994.

# APPENDIX A
## MEND Board of Directors Members

Mr. Henry Brehaut
Senior Vice-President, Environment
Placer Dome Inc.

Mr. H.A. (Tony) Clarke
Assistant Deputy Minister
Environment Canada Conservation and Protection

Dr. W.R.(Dick) Cowan, Director
Ministry of Northern Development & Mines
Ontario

Dr. Marc-Denis Everell
Assistant Deputy Minister
Mineral & Energy Technology Sector
Natural Resources Canada

Mr. Charlie Ferguson
Vice-President, Environment Health & Safety
INCO Limited

Mr. Wayne Fraser
Director, Environmental Control
Hudson Bay Mining & Smelting Co.

Mr. Gérald Gauthier
Senior Vice-President, North American Operations
Lac Minerals Ltd.

M. Louis P. Gignac
President
Cambior

Dr. Irwin Itzkovitch
Director, Mineral Sciences Laboratories
CANMET

Mr. Walter J. Kuit
Manager, Environmental Affairs
Cominco Ltd.

M. Jacques Lebuis
Sous-ministre associé aux mines
Ministère de l'Énergie & des ressources du Québec

Mr. Mike P. Lipkewich
Senior Vice-President, Mining
Teck Corporation

M. André Marsan
Sous-ministre adjoint, Opérations
Ministère de l'environnement du Québec

Mr. Bruce McRae
Assistant Deputy Minister
Energy, Mines & Petroleum Res.
British Columbia

Dr. C. George Miller
President
Mining Association of Canada

Mr. John S. Rayner
Assistant Deputy Minister
Northern Affairs Program
Department of Indian and Northern Affairs

Mr. Larry Seeley
Vice-President, Environmental Services
Falconbridge Limited

Mr. Al Taylor
Canadian Environmental Network

Mr. David Tomasson
Deputy Minister, Manitoba Energy and Mines

Mr. John White
Vice President, Mine Development
Noranda Minerals
Chairman, MEND Board of Directors

**Resource Persons:**

| | |
|---|---|
| Mr. D.G. Feasby | Manager, MEND Secretariat, CANMET |
| Mr. M.P. Filion | Director, Environmental Affairs, Teck Corporation |
| Mr. H. Veldhuizen | Vice-President, Environment, Noranda Minerals Inc. |
| Mr. P. Reid | President, Mining Association of Ontario |

## MEND Management Committee Members

Mr. Art Ball, Director of Mines
Manitoba Energy & Mines

Mr. Ron Barsi
Director, Saskatchewan Mineral Industry
Environmental Protection Branch

Dr. Dick Cowan
Director, Mining and Land Management
Ontario Ministry of Northern Development & Mines

Dr. John Errington, Manager, Reclamation
B.C. Ministry of Energy, Mines & Petroleum Resources

Mr. Grant Feasby
Manager, MEND Secretariat
CANMET

Mr. Mike Filion
Director, Environmental Affairs
Teck Corporation

Mr. Wayne Fraser, Director of Environment
Hudson Bay Mining & Smelting Co.

M. Claude Gignac, Ingénieur
Ministère de l'environnement du Québec

Mr. Ron Hore, Regional Director
Ontario Ministry of Environment

Mr. Tom Hynes
Program Principal, Acid Mine Drainage
CANMET

Dr. Irwin Itzkovitch
Director, Mineral Sciences Laboratories
CANMET

Dr. Ed Kustan
Manager, Environmental Assurance
INCO Limited

Dr. Joseph Lazarovich
Director of Mineral Resources
Dept. of Indian and Northern Affairs

Mr. Sam McEwan, Director of Mineral Development
N.B.Department of Natural Resources & Energy

Mr. Ferd Morrissey, Manager, Engineering Analysis
Newfoundland Department of Mines and Energy

Dr. George Poling
Professor of Mineral Process Engineering
University of British Columbia

Mr. Jim Robertson
Manager, Environmental Engineering
Placer Dome Inc.

M. Gilles Mahoney
Directeur de l'industrie minérale
Ministère de l'énergie et ressources

Mr. Michael Sudbury
Director, Environmental Services
Falconbridge Limited

Mr. Leonard Surges, Director, Environment
Brunswick Mining and Smelting Corporation Ltd.

Mr. Victor Buxton
Director, Industrial Sectors Branch
Environment Canada

Mr. Al Vivyurka
Senior Environmental Engineer
Rio Algom Limited

Mr. Ken B. Yuen
Director Oceanography & Contaminants Branch
Fisheries and Oceans Canada

Mr. Bernie Zgola
Head, Decommissioning & Mine Impacts Section
Atomic Energy Control Board

Mr. Andy Cormier, President and General Manager
NB Coal Limited

Mr. Ferd Morrissey
Manager, Engineering Analysis
Dept of Mines and Energy

Mr. Dan Kahn, Mining Engineer
Nova Scotia Department of Natural Resources

**Resource Persons:**

Mrs. M. Blanchette, Coordinator, MEND Secretariat, CANMET
Mr. G. Tremblay, Coordinator, MEND Secretariat, CANMET

Mrs. K. Mailhiot, Coordinator, MEND Secretariat, CANMET

# APPENDIX B
## Projects Completed Before 1993

| Number | Titles: |
|---|---|
| 1.11.1 | AMD from Waste Rock - Literature Review |
| 1.14.1 | Field Evaluation Rock Hydrochemistry - Mine Doyon Phase I |
| 1.15.1 | AMD from Open Pits - Equity Silver |
| 1.16.1a | Evaluation of Predictive Techniques |
| 1.16.1b | Manual of Chemical Evaluation Procedures |
| 1.16.1c | Development of Static Evaluation Procedures |
| 1.17.1 | Hydrogeochemical Investigation - Waite Amulet Reactive Tailings |
| 1.21.1a | Evaluate RATAP.BMT2 Capabilities |
| 1.21.1b | Workshops of Modelling Techniques - Tailings |
| 1.21.1c | Modelling of Reactive Tailings - Prepare RATAP Users Manual |
| 1.24.1 | Development of Preliminary Modelling of Seepage Quality from Acid-generating Waste Rock Dumps |
| 1.41.1 | International Waste Rock Modelling Workshop |
| 2.11.1a-c | Evaluation of Existing Underwater Disposal Sites |
| 2.11.1d | Peer Review on the Subaqueous Disposal of Tailings |
| 2.14.1 | Establish Vegetative Wetlands over Tailings |
| 2.21.1 | Engineered Dry Covers for Tailings |
| 2.22.1 | Assessment of Hardpan |
| 2.23.1 | Documentation of Disposal Methods for Tailings and Waste Rock (Draft Acid Rock Drainage Technical Guide) |
| 2.24.1 | Vegetation Manual "Manual of Methods used in the Revegetation of Reactive Sulphide Tailings Basins" |
| 2.31.1a | Dry Covers on Waste Rock - Heath Steele |
| 2.32.1 | Blending and Segregation of Waste Rock - Kutcho Creek |
| 2.32.2a | Co-Disposal of Tailings and Waste Rock in Cells - Les Mines Selbaie |
| 2.33.1 | ARD Remediation Measures at Four Norwegian Mines |
| 2.41.1a | Electrochemical Oxidation/Passivation of Sulphides |
| 2.44.1 | Microbial Plugging of Mine Tailings to Reduce the Production of AMD |
| 3.11.1a-c | Treatment of Acidic Seeps Using Wetland Ecology and Microbiology |
| 3.12.1 | Assessment of Existing Natural Wetlands |
| 3.21.1a | Metals Recovery from Acid Mine Drainage |
| 4.1.1 | Field Methods Manual - Tailings |
| 4.3.1 | Standard Reference Materials - Tailings |

Continued...

## Projects Completed Before 1993 - Continued...

| Number | Titles: |
|---|---|
| 4.5.2 | Field Sampling Quality Assurance/Quality Control (QA/QC) |
| 4.7.1 | Optimum Sampling Frequency |
| 4.7.2 | Biological Monitoring of Acid Mine Drainage |
| 4.7.3 | Aquatic Invertebrate Monitoring |
| 4.7.4 | Acid Mine Drainage Sediment Monitoring |
| 4.7.5 | Ion Speciation |
| 4.7.6 | Paleolimnology Techniques |
| 5.4.1 | Acid Rock Drainage Technical Guide - version franēaise |
| 5.5.1 | Preliminary MEND Research Plan |
| 5.6.1 | Second International Conference on the Abatement of Acidic Drainage |

## PREDICTION

**Project 1.11.1:** **AMD from Waste Rock - Literature Review**
**Expenditures:** **$50,000**

**A critical review of existing information on acid-generating waste rock has been carried out as a basis for further work. Relevant information on theory, experiments, modelling and field studies were assessed for their validity and applicability. The impact of various construction techniques on phase migration, solid, liquid, and gas, were assessed. Water movement and solids migration within rock piles were found to be dependant on hydraulic conductivity, hydraulic gradients, degree of saturation, and laminar versus turbulent flow. Solids migration was defined in terms of internal migration and geotechnical failures, and gas transport, primarily through gaseous advection. The primary reactions were identified as: acid generation, which may be driven by abiotic and biological factors; acid neutralization; and metal leaching. Acid neutralization is a highly complex series of aqueous and mineral reactions. Speciation analyses were identified as useful but under-utilized. The parameters associated with the rate and extent of metal leaching were identified and discussed. This review is available as a MEND report.**

**Project 1.14.1:** **Field Evaluation Rock Hydrochemistry - Mine Doyon Phase I**
**Expenditures:** **$362,000**

**Initial dump characterization of the 21 million tonne Mine Doyon waste rock pile in Québec was carried out through review and evaluation of all available site documentation. Indepth characterization (physical, chemical and hydrological) was done using: boreholes penetrating the entire thickness of the rock pile and into the bedrock; boreholes along the perimeter to sample groundwater; exploration pits to observe alteration phenomenon; and weir stations in the drainage ditches to measure water flow. An inventory and assessment was made of all granular material available for use as a (composite) dry cover, but although suitable materials were identified, differential compaction in the dump due to weathering does not favour the installation of a natural cover. Based on heat and mass balances it is estimated that 7000 tonnes of pyrite (<1% of total) oxidize per year and that the amount of pyrite in the dump has not been significantly depleted. Temperature profiles indicate that oxidation is in a steady state and may be maintained for at least another 100 years. More detailed studies related to prediction are ongoing (1.14.2). A comparison of mineralogical content with leachate chemistry will help understand reactions of leachate formation and transformation.**

**Project 1.15.1: AMD from Open Pits - Equity Silver**
**Expenditures: $53,000**

The overall objectives were to assess relative contributions of AMD sources in open pits and to develop an applicable computer model of such a system. All relevant information on water movement and chemistry on and within mine walls was reviewed. Acidic conditions appear to be at least partially due to unsaturated fractures. The rates of acid generation and neutralization on exposed pit walls of the Main Zone Pit at Equity Silver in British Columbia were determined using field studies and existing mine data. The importance of detailed baseline studies of groundwater prior to mining was emphasized. Metal leaching is strongly dependant on aqueous speciation and mineral solubility. A computer code, MINEWALL was created to simulate open pits during operation and decommissioning and applied using site-specific information. In the case of Equity Silver, it was predicted that the flooded pit would return to neutral after the initial acid flush. MINEWALL has undergone preliminary verification but was not finalized for general use. Further development is ongoing (1.15.2).

**Project 1.16.1a: Evaluation of Predictive Techniques**
**Expenditures: $63,000**

To predict the generation of acid mine drainage from mine wastes, there are several methods available of varying complexity. These methods have been evaluated to assess their reliability when applied to the field and to recommend those with the most promise for determining the potential for generating acid drainage. The following documented chemical prediction static and kinetic procedures were evaluated and compared: B.C. Research Initial test; Acid Base Accounting; Sulphur Ratio test; $H_2O_2$ for Pyrite Estimation; B.C. Research Confirmation test; Humidity Cell test; Shake Flask Weathering test; Soxhlet Extraction test; and Manometric Carbonate Pressure Analysis. In addition three more recently developed tests were evaluated: Net Acid Production test; Modified Biological Confirmation test; and Modified Acid Base Accounting. Evaluations were carried out by performing each procedure on eight tailings samples and four waste rock samples from Canadian mines. The advantages and limitations of each method are discussed. The documentation of the above procedures in a detailed users manual format was recommended (1.16.1b).

**Project 1.16.1b: Manual of Chemical Evaluation Procedures**
**Expenditures: $23,000**

A user's guide has been produced for the application of chemical evaluation procedures (identified in 1.16.1a) for the prediction of acid generation from mining wastes and related materials. The manual provides background information on acid generation from mine wastes and applicable references. An integrated approach to acid mine drainage prediction strategy is also outlined. Guidelines to the application of the individual prediction tests, details of procedures and associated considerations are addressed. The balance of the manual is devoted to the detailed descriptions of recommended and alternative chemical predictive procedures. Six static (short term) methods and five kinetic (longer term) methods are described. For each method, the applicability, objectives, advantages and disadvantages are discussed. The test principles, equipment and reagent requirements, test procedure interpretation and manner of result reporting are outlined in detail. To date there is no single chemical predictive method that is applicable to all waste materials and/or situations. Further development is seen as essential (1.16.1c).

**Project 1.16.1c: Development of Static Evaluation Procedures**
**Expenditures: $21,000**

As part of the overall program to identify and evaluate techniques for predicting the potential for tailings and waste rock to produce contaminated run-off and seepage, further applicable static procedures were identified and assessed. Based on a review of the chemical literature four methods were ranked by among other parameters: cost; rapidity and robustness; and selected for preliminary testing using samples of known mineralogical composition. The methods tested were: determination of sulphur as pyrrhotite and pyrite; field determination of sulphur as pyrite; modification of the conventional U.S. EPA neutralization potential procedure by filtration of leachate and addition of hydrogen peroxide; and determination of carbonates by metal analysis. The first procedure performed well but further development of the latter three was considered necessary. Methods to directly and quantitatively determine Ca and Mg carbonates are not commercially available and modification of the third procedure is recommended to address this problem. It was underlined that routine acid-base accounting should include a supporting mineralogical description to provide confidence in the predictive chemical results.

**Project 1.17.1:** **Hydrogeochemical Investigation - Waite Amulet Reactive Tailings**
**Expenditures:** **$285,000**

**This multi-year hydrogeochemical baseline field study was designed to develop a better understanding of the hydrology and hydrogeochemistry occurring in acid-generating tailings ponds. The data were also collected to be used to assess/refine existing predictive models (1.21.1a) and provide guidance in the development of new models and control techniques. Preliminary site reconnaissance along with piezometer installation and sampling of tailings and pore water allowed an assessment of the tailings and underlying hydrogeologic characteristics such as pore water chemistry, water table and tailings depth, mineralogy, hydraulic conductivity, direction of flow, and biological activity data. Further data collection completed the definition of the site hydrogeology. The unsaturated zone geochemistry under clay covered, directly vegetated and untreated sites and along the dam face was evaluated. Oxidation control options were defined. A water and metal balance for the tailings site was completed by monitoring precipitation, evaporation, and the flow and quality of the seepage at the face and the surface. The mineralogy of the unsaturated zone was defined and related to pore water chemistry using computer models. Oxygen diffusion versus depth into the tailings was determined. The study verified that the most important control on pyrite oxidation is the availability of oxygen, which influences production of ferric iron and bacterial population density. Oxygen diffusion was considered horizontally as well as vertically.**

**Project 1.21.1a:** **Evaluate RATAP.BMT2 Capabilities**
**Expenditures:** **$30,000**

**Originating from work in the mid 1980's by CANMET, the Reactive Acid Tailings Assessment Program for Base Metal Mines (RATAP.BMT) was developed as a predictive modelling tool to: investigate the parameters which control sulphide mineral oxidation in tailings; simulate such acid generation; estimate acid generation potential in the long term; and evaluate control measures. The capabilities and limitations of the RATAP.BMT2 model were evaluated, including calibration of the model using Waite Amulet field data (1.17.1) and critical assessment of the concepts on which the model is based. Part of the data was used to calibrate the site dependent parameter estimates and the rest to verify the model both in the temporal**

**and spatial sense. Modifications were made to the model where required. The modelled constituents included: temperature; pH; oxygen concentration with depth; and porewater concentration of sulphate, ferrous and ferric iron, dissolved copper and zinc. Further review of the model has been made (1.21.1b) and with more recent revisions, a manual has been generated (1.21.1c) for the current version, RATAP.BMT3, available through CANMET.**

**Project 1.21.1b: Workshops of Modelling Techniques - Tailings**
**Expenditures: $73,000**

**An international workshop was held on modelling of reactive tailings, to assess the current capabilities and the perceived requirements (industrial, regulatory). The workshop was held in Haliburton, Ontario on May 23 & 24, 1990, and was attended by participants from Canada, Sweden, United States, and Australia, representatives from the mining industry, the consulting community, universities and various governmental departments. The presentations and discussions concentrated on the simulation model, RATAP.BMT2, capable of calculating the generation of sulphuric acid from reactive tailings. Other presentations provided a consulting engineering perspective, the industry perspective and the point of view of the regulatory agencies for the use of models. Finally, representatives of the United States, Sweden and Australia presented their assessment of current capabilities. The use of programmed models capable of calculating the characteristics of reactive tailings and their impact on the environment was discussed. It was recommended that the RATAP.BMT2 predictive model should be made available to potential users for evaluation before more development of the model was undertaken, and that a users manual should be made available with the model (1.21.1c).**

**Project 1.21.1c: Modelling of Reactive Tailings - Prepare RATAP Users Manual**
**Expenditures: $19,000**

**The mathematical model, Reactive Tailings Assessment Program (RATAP), was designed to predict, in the long-term, the quantity of acid generated by oxidation of pyrite in uranium mill tailings. This model was adapted to base metal tailings, and at the international modelling workshop in May of 1990 (1.21.1b), it was recommended that the model be prepared for distribution to potential users for application to AMD sites. RATAP.BMT3 is a complex model with over 250 input parameters, not lending itself to easy use. Therefore a module to facilitate inputting initial condition data and a second module to facilitate the acquisition and display of**

output data from model simulations were developed. This combination provides a powerful user-friendly predictive tool. A user's manual was prepared for the software ensemble. As recommended, an overview document has been prepared for RATAP.BMT3 to assist the potential user. This has been prepared, not as a separate document but as part of the input module, giving an overview of the models intended purpose and applications, estimated simulation capabilities, limitations, and expansion potential. Both model and manual are being distributed through the Canada Centre for Mineral and Energy Technology (CANMET).

| | |
|---|---|
| **Project 1.24.1:** | **Development of Preliminary Modelling of Seepage Quality from Acid-generating Waste Rock Dumps.** |
| **Expenditures:** | **$21,000** |

The project was originally scoped to follow the complete development and abandonment of a 15 million tonne dump, over the course of four years. A variety of factors led to a much reduced scope of work, although it was recommended that the predictive modelling of AMD from waste rock be pursued. Collection and description of selected drill core samples from the Yukon (Curragh Resources) were carried out on site for dump material characterization. Key physical and chemical parameters were generally identified for the monitoring of reactive waste dumps. A conceptual model of the physical and geochemical nature of waste dumps was developed based on the existing literature and the incorporation of the parameters above. The development of such a model was recommended and would guide future assessment and design of instrumentation requirements for reactive waste rock dumps (1.26.1). The complexity of the modelling effort and potential scope of the study has however, been recognised.

| | |
|---|---|
| **Project 1.41.1:** | **International Waste Rock Modelling Workshop** |
| **Expenditures:** | **$7,770** |

A three day international workshop on modelling the generation and transport of acid rock drainage from mining waste rock was hosted by MEND in late September, 1992. Its purpose was to focus research and development of modelling capabilities for waste rock dumps to the needs and requirements of users by identifying: current (international) capabilities and shortcomings; and industry/regulatory requirements.

It was suggested that a useable model should incorporate the following: oxygen and heat transport; solute movement and hydrology; and geochemistry. Oxygen and heat transport can

**be modelled although further field assessment of relevant parameters was recommended. The area of solute transport and hydrology under mainly unsaturated conditions is less advanced. The geochemical processes are considered the most difficult, and in some cases simulation may not be possible. Among other actions, a critical review of the key geochemical processes and associated current modelling capabilities (1.42.1) was recommended to assess the potential for incorporation of geochemistry into the overall predictive capacity. The workshop proceedings are available through the MEND secretariat.**

## PREVENTION AND CONTROL

**Project 2.11.1a-c:** **Evaluation of Existing Underwater Disposal Sites**
**Expenditures:** **a: $220,000 b: $136,000 c: $67,625**

The objective of this project was to evaluate the effectiveness of underwater disposal of reactive wastes by evaluating representative existing sites, examining the impacts which result when in-lake disposal systems are used, and recommending criteria for the safe underwater disposal of tailings. Initially (2.11.1a), all known Canadian sites were documented and water quality results obtained from existing sources (1988/89). Field surveys were done on 4 sites during the summer of 1989 (Buttle and Benson Lakes in B.C., Anderson and Mandy Lakes in Manitoba). Geochemical assessments were conducted at Anderson and Mandy Lakes in Manitoba in 1990 (2.11.1b). Two projects were completed on Benson Lake in 1991-1992. The first project focused on the chemical and biological aspects of changes in Benson Lake following subaqueous tailings disposal. The second project used Keogh Lake, a pristine, hydrographically similar "control lake" to permit geochemical comparison between lakes with tailings and without tailings.

**Project 2.11.1d:** **Peer Review on the Subaqueous Disposal of Tailings**
**Expenditures:** **$34,350**

At the request of the MEND Board of Directors, a scientific and technical review of all aspects of the work to date was recommended (2.11.1d). The future direction of the subaqueous tailings disposal program will be based on the results of the peer review.

The objectives of this project were to provide technical and scientific assessment of MEND studies on subaqueous disposal of tailings, and to outline additional requirements necessary for the MEND studies to maintain a credible scientific approach. The Peer Review was carried out by The Rawson Academy of Aquatic Science with the aid of highly qualified and experienced scientists, each a specialist in one or more fields of science dealing with aquatic ecosystems. The reviewers agreed that the work carried out to date on the three lakes reviewed, Mandy, Anderson and Buttle (Benson was not reviewed because work there was not complete) was well done. The review identified key areas that are lacking in information. For instance, the studies of background limnologies for the lakes were not suitable to present to regulatory personnel, the seasonal and yearly changes that occur in the water column loadings would have to be addressed and the field experiment for metal flux measurements, although well done, do not assess the quantitative fluxes which are considered important. Some additional literature reviews (e.g. metal toxicology) and a complete program for documenting QA/QC were suggested and the definition of the types of additional field data (e.g.

geochemical) and methods for data collection were presented in the report. Additional work to develop a more complete understanding of the sites under study was recommended.

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|---|---|
| **Project 2.14.1:** | **Establish Vegetative Wetlands over Tailings** |
| **Expenditures:** | **$30,000** |

The objective of this project was to develop a technique for the reclamation of high iron sulphur tailings by establishing a marshland or perched water table above the tailings. The project was initiated in 1986, when a total of 9 test cells with different surface covers and amendments were constructed at the Fault Lake tailings site in Falconbridge. The covers were kept wet and the porewater quality and metal loading of the unoxidized tailings were monitored for three field seasons. Two important recommendations resulted from this study: first, to establish a marshland or perched water table above the tailings, one must define the hydrology of the site to define the water table and the groundwater fluctuations; and second, one must determine the hydraulic conductivity and gas permeability of the tailings. In these trials, coarse tailings resulted in high water/gas permeabilities and a perched water table could not be maintained without continuous irrigation.

| | |
|---|---|
| **Project: 2.21.1:** | **Engineered Dry Covers for Tailings** |
| **Expenditures:** | **$216 000** |

The objective was to develop laboratory and computer methodologies for testing, designing, placing and evaluating the effectiveness of engineered soil covers for reactive sulphide wastes. Practical concepts were proposed for designing high performance soil covers using locally available natural materials. Critical material properties required for design and prediction of performance were identified and these were obtained using specially designed laboratory columns. A computer model describing oxygen diffusion in soil covers was also developed and is currently being used in the demonstration column work for different cover projects (e.g. large scale tests at Waite Amulet (2.21.2) and Heath Steele (2.31.1)). These evaluation techniques and standardized laboratory procedures will permit the testing of candidate soils from which the full-scale results can be modelled and predicted.

| | |
|---|---|
| **Project 2.22.1:** | **Assessment of Hardpan** |
| **Expenditures:** | **$100,500** |

The project was designed to characterize the mineralogy of hardpan and to assess if it can be stabilized and used as an oxygen barrier. Petrographic studies and permeability tests were conducted on selected hardpan samples from four Manitoba tailings sites. The general properties of hardpan were initially found to be encouraging as a relatively impervious and

**resistant zone was observed. Weathering and seasonal frost, however, tend to break down the hardpan, resulting in a fractured, softened zone which possesses only moderate resistance to infiltration and continuous oxidation. As a result, serious doubts remain concerning the use of hardpan to control the acid generation process. Also, no suitable method of artificially creating hardpan was determined and the project was terminated.**

**Project 2.23.1 Documentation of Disposal Methods for Tailings and Waste Rock (Draft Acid Rock Drainage Technical Guide)**
**Expenditures: $75,000**

**A comprehensive manual was prepared which provides an introduction to acid rock drainage (ARD) and direction on how best to deal with the problem. Techniques are discussed with respect to the handling of waste rock, tailings, open pits and underground workings. Current approaches in other parts of Canada and the world are also described. The manual has been prepared as a "how to" document and is being distributed in loose leaf binder format so that the manual can be easily updated in the future. The BC AMD Task Force recommended that the monitoring section (Chapter 11) of the Technical Guide be upgraded to incorporate recent developments in monitoring techniques, sampling equipment, data manipulation and statistical treatment (4.5.3)**

**Project 2.24.1: Vegetation Manual "Manual of Methods used in the Revegetation of Reactive Sulphide Tailings Basins"**
**Expenditures: $33,500**

**The manual provides a comprehensive description of procedures for preparation, neutralization, seeding and follow-up maintenance, if required, for revegetation of reactive sulphide tailings disposal areas in Canada. It describes and illustrates some of the more common agricultural equipment and fundamental, basic techniques required to prepare, seed and maintain mine waste areas revegetated. Case histories are appended that outline reclamation programs carried out at several Canadian mines including Falconbridge, INCO and Noranda.**

**Project 2.31.1a: Dry Covers on Waste Rock - Heath Steele**
**Expenditures: $312,000**

**Acidic drainage generation in waste rock poses a much different problem from that of tailings because of the huge difference in the particle sizes of the waste material. Waste rock piles contain large voids which allow water and air to freely penetrate the pile and these conditions promote accelerated bacterial and chemical reactions. The objective of the project was to evaluate the effectiveness of engineered natural covers for reactive sulphide waste rock at the**

Heath Steele mine site. Locally available cover materials were sampled and characterized according to standard soil properties. A column apparatus was used to measure the rate of oxygen diffusion through potential cover materials (2.21.1). Based on the results of the laboratory testing a practical, composite cover was designed using native materials. In order to confirm the effectiveness of the proposed cover it was recommended that the cover be field tested (2.31.1b).

### Project 2.32.1 Blending and Segregation of Waste Rock - Kutcho Creek
**Expenditures: $ 140,000**

The objective was to evaluate, through laboratory and field analysis, the effectiveness of segregating and blending acid-generating waste rock and alkaline material as a method of preventing or controlling AMD. Acid-base accounting tests were used to identify the materials and humidity cell tests composed of blended ratios demonstrated that the rate of acid generation was reduced. Results from the test pads were not as conclusive as the laboratory results. It was discovered that leachate quality was dependent upon flushing rates as opposed to the actual acid generation rate. Long-term predictions, based on the results from the humidity cell test work, show that the neutralizing potential could be consumed in as early as 100 weeks with acidic conditions continuing until all sulphides were oxidized. A separate analysis has determined that the costs associated with blending large amounts of waste materials in a full scale waste dump would be excessive. Based on these predictions, blending of Kutcho waste rock, even at 1:1, would not be a viable option. No follow-up work was recommended.

### Project 2.32.2a Co-Disposal of Tailings and Waste Rock in Cells - Les Mines Selbaie
**Expenditures: $96,000**

The objective of the project was to evaluate the concept of co-disposing reactive sulphide waste rock with non-reactive tailings in basins to minimize acidic drainage from the waste rock. The design seeks to create saturated conditions in the reactive waste and minimize groundwater flow in the basin. Phase (a) consisted of field reconnaissance, characterization of both tailings and waste rock and potential basin construction materials, and a preliminary geotechnical design of the basin. The prediction tests carried out on the tailings materials indicated that the tailings are likely to generate acid. The project was based on the concept of co-disposing acid-generating waste rock with neutral tailings. Since the tailings are likely to be acid producers, the final design of the basin was changed to rely on low permeability dykes to maintain saturated conditions in the waste rock and tailings. This was not the original concept and no follow-up work was recommended.

**Project 2.33.1** ARD Remediation Measures at Four Norwegian Mines
**Expenditures:** $38,500

The project was undertaken to provide a transfer of information of full-scale remediation measures used at four sulphide mines in Norway. The study addresses operational difficulties, procedures, results and costs of natural sulphate reduction (Lokken mine), natural convection as an evaporative treatment process (Killingdal mine), geomembrane covers (Kjoli mine) and underwater disposal (Skorovas mine). The final report makes conclusions and recommendations about the remediation methods used at the four sites.

**Project 2.41.1a:** Electrochemical Oxidation/Passivation of Sulphides
**Expenditures:** $60,000

The objective was to develop electrochemical methods for the prevention of atmospheric oxidation, acid generation and leaching of sulphide tailings. In this project, it was established that a passive iron oxide film grown on pyrite/pyrrhotite can protect the substrate from oxidation on exposure to air and hence prevent acid generation. It was also shown that a bed of pyrrhotite rich tailings can be converted into a hardpan by a cathodic treatment followed by exposure to air under moist conditions. Six weeks after switching the current off, the bed automatically consolidated into a hardpan with some expansion. The solution percolating through this bed in the earlier stage of hardening had a pH of 5.5 and the iron concentration was lowered to natural equilibrium values. Following a progress review meeting, it was recommended that the project not continue to larger scale tests. However, the concept of in situ formation of synthetic hardpan by surface chemical treatment, briefly presented in Phase I, was recommended to the New Ideas Task Force for consideration.

**Project 2.44.1:** Microbial Plugging of Mine Tailings to Reduce the Production of AMD
**Expenditures:** $100,000

The objective of the project was to evaluate, at a laboratory scale, the microbial plugging technology as a method of reducing the production of AMD. The project involved the use of starved indigenous microorganisms called ultramicrobacteria's (UMB's) which, when exposed to nutrients, reproduce and excrete polymers. The polymers fill the void spaces in the tailings, effectively creating a microbial plug capable of reducing both the penetration of oxygen and water. The conclusions of the study were that: it was not demonstrated that a microbial cap could significantly reduce the permeability of the tailings over long periods of time; a decrease of the oxygen penetration was observed for the columns that received nutrients; an increase in

**pH was observed for all of the permeates from the columns that received nutrients; and addition of UMB's to the tailings was not necessary because native strains were present in the tailings. It was also noted that although a reduction in permeability was not observed in the experiments, it is possible that in fine textural tailings, a significant reduction in water permeability would be expected. No follow-up work was recommended.**

## TREATMENT

**Project 3.11.1a-c:** **Treatment of Acidic Seepages Employing Wetland Ecology and Microbiology - Phases A, B and C**
**Expenditures:** **$679,000**

This project was designed to investigate the use of microbiology and ecology of wetlands to reduce acid mine drainage. A major objective was to develop design parameters for the Acid Reduction Using Microbiology (ARUM) process. The project had the following phases: a), Conduct microbiological nutrient requirements and cellulose degradation studies in the laboratory, and set up field systems at Elliot Lake and Copper Cliff; b), Microbiological and water quality monitoring and conduct process capability tests; c), Monitor system performance and make final adjustments; and d), Monitor and establish performance criteria for operating systems.

The key results related to water quality; significant alkalinity was created (27 kg/tonne of water) and the heavy metals were precipitated as sulphides. However, the system appeared to be capable of handling only low flows, less than 3 to 5 litres/minute. At the very low flow of 1 litre/minute, very good water quality had been produced. The Treatment committee carefully reviewed the results achieved to the end of 1991 and recommended that the final year's monitoring and determination of performance criteria be completed (3.11.1d).

**Project 3.12.1:** **Assessment of Natural Wetlands Affected by Low pH / Metal Contaminated Seeps**
**Expenditures:** **$40,000**

The study examined natural wetlands near six base metal mines in Eastern Canada for evidence of biological mitigation of acidic drainage. Potentially suitable wetlands were identified and a field program was conducted to describe and compare these sites in terms of water and sediment chemistry, hydrology, and vegetation. The project was started too late to conduct a summer campaign; only fall results were obtained. There were large differences between the wetlands in terms of metal loadings, groundwater inputs, water retention times, metal concentrations in wetland sediments, and vegetation communities. None of the sites, however, appeared to significantly reduce downstream loadings of metals or acidity levels during the fall. Prolonged drought at one site severely reduced flows and prevented the calculation of influent and effluent metal loadings. The apparent lack of biologically-related improvement of AMD was most likely a consequence of (1) low temperatures, ca. 4°C, (2) channelized flow patterns within the wetlands, and (3) limited contact of acidic drainage with anoxic sediments. Inputs from other seeps and groundwaters to the wetlands were significant complicating factors, especially at the Kam-Kotia site. High metal concentrations in wetland sediments indicated that the wetlands had removed metals in the recent past.

**Project 3.21.1a:** **Metals Recovery from Acid Mine Drainage - Phase A**
**Expenditures:** **$25,000**

**A background survey and a review of technology were completed on methods which could remove metals such as Cu, Ni, and Zn from acidic drainage and reduce the potential toxicity of treatment sludges. A summary report was completed in November 1991. Three technologies were determined to have economic and technical potential. They were; copper cementation, ion exchange, and selective precipitation. Since cementation is a well defined and frequently used method, ion exchange and selective precipitation of metals were the methods recommended for further research. These methods were assessed in projects initiated in 1992. It was indicated that a cross-Canada survey of acid drainage water quality was needed (3.22.1).**

## MONITORING

### Project 4.1.1: Field Methods Manual - Tailings
**Expenditures: $29,000**

**Accurate monitoring of a tailings impoundment requires that the samples collected for physical, chemical and microbiological analyses be of high quality. A manual of sampling methodologies applicable to tailings impoundments and involving the collection of representative solid, liquid and pore-gas samples was prepared. It offers guidance and recommendations on the selection of methods, emphasizing minimal sample disturbance and contamination. For each method, the objectives, descriptions, advantages and disadvantages are presented. Flowcharts are presented to summarize the methods and guide in their selection. A summary of quality control recommendations defined in the three primary chapters is also presented.**

### Project 4.3.1: Standard Reference Materials - Tailings
**Expenditures: $50,000**

**The key to reliable and reproducible analytical results is the availability of good, relevant standard reference materials. CANMET has an established Canadian Certified Reference Materials Program (CCRMP) through which four mill tailings materials were selected, prepared and certified. The four samples were prepared as composite reference materials from pyrite/pyrrhotite tailings from INCO, Falconbridge and Noranda. Analyses of nineteen major and minor elements were performed by seventeen laboratories on six replicates for each of the four standard materials. The reference materials, RTS-1, RTS-2, RTS-3, and RTS-4, are currently available through CANMET with all applicable supporting documentation.**

### Project 4.5.2: Field Sampling Quality Assurance/Quality Control (QA/QC)
**Expenditures: $9,500**

**A literature review has been completed on field sampling criteria with particular emphasis on quality assurance and quality control protocols. The focus is on components of programs for predicting or detecting acid mine drainage and its environmental effects. Data quality objectives must be set which define the level of uncertainty that a decision maker is willing to accept. The report reviews the elements of field QA/QC programs for sampling surface and groundwater, effluents, sediments, soils, tailings and waste rock for chemical parameters related to AMD. It also reviews QA/QC programs for: stream flow measurements and biological effects monitoring, including sampling populations of fish, benthic invertebrates, periphyton, zooplankton, and phytoplankton; metals in fish tissue; and the presence of *Thiobacillus ferrooxidans*. Although the elements of QA/QC programs for laboratory analyses**

are reasonably well defined with respect to the assessment of acid mine drainage it is recommended that more emphasis be placed on the implementation of QA/QC protocols for field programs.

**Project 4.7.1: Optimum Sampling Frequency**
**Expenditures: $27,000**

The project objective was to determine optimum water quality sampling frequencies and most representative, measurable parameters (eg. pH, conductivity) for AMD effluent by evaluating four of the most extensive water quality data sets associated with acid mine drainage in British Columbia. A number of potential failings were discussed, including: fixed-frequency single samples used in mean loading estimates; inaccurate or incomplete flow estimates; significant short-term events; and the overemphasis of analytical accuracy versus timely, representative sampling. It is recommended that acid mine drainage monitoring schedules be revised to consider the information needed for management; ie., accuracy, lag times, risks, and parameter variation (spacial and temporal). As well, pre-operational studies at proposed mine sites should include measures of natural variation and should span seasons of anticipated high acid mine drainage discharge to obtain adequate baseline data.

**Project 4.7.2: Biological Monitoring of Acid Mine Drainage**
**Expenditures: $21,000**

The objectives were to determine the most effective methods for biological monitoring of acid mine drainage through a review of existing methods and assess and recommend the most effective techniques. A variety of indicators are suitable for detecting impacts of AMD, but few have been linked to chronic whole organism responses. The most promising and proven biological monitoring techniques, however, include: benthic community responses; growth and reproductive parameters of fish populations; survival in a designated zone of impact; and other changes at the individual, biochemical level. It was determined that no single approach to the problem of biological effects monitoring will completely satisfy present needs. the most cost-effective approach to assessing ecosystem health in waters affected by AMD was found to involve a multi-disciplinary, "top-down" approach, which relies on the detection of impacts before they become irreversible.

## Project 4.7.3: Aquatic Invertebrate Monitoring
**Expenditures: $136,130**

A three year research project was aimed at evaluating a trough apparatus for measuring the environmental effects of acid mine drainage on aquatic invertebrates. The study was carried out at Equity Silver in British Columbia to address allowable dilution rates of treated acid mine drainage discharged into Foxy Creek near the mine.

In the first year a flow-through trough apparatus was constructed to test preselected concentration of treated acid mine drainage. The apparatus accurately determined ecosystem response curves for effluent discharges as indicated in the available report titled "The Effect of treated AMD on Stream Macroinvertebrates and Periphytic Algae: An in situ Mesocosm Experiment". Ensuing work involved monitoring chemical and biological changes in a stream mesocosm that was dosed with a gradient of AMD from Equity Silver. Among other conclusions, the report, "Stream Community Responses to a Gradient of Acid Mine Drainage Additions" indicated that the metal concentration in solution which causes a change in community structure may be lower when that metal is part of a complex solution of metals. Models of indices of benthic response to the gradient of AMD additions were generated and compared to the CCREM guidelines.

## Project 4.7.4: Acid Mine Drainage Sediment Monitoring
**Expenditures: $6,500**

This project was designed to review all available literature pertaining to sediment monitoring techniques and to recommend the relevance and applicability of these techniques for measuring the impact of AMD. The review focused on assessment of sediment quality through sediment chemistry, bioassay testing and benthic macroinvertebrate community structure. Analytical methods for sediment chemistry are reviewed and summarized. Sampling devices, design, handling and preparation are evaluated with respect to sediment toxicity testing. Freshwater sediment bioassays with bacteria, algae, invertebrates and fish are reviewed. Guidelines for sediment chemistry, bioassay testing and benthic macroinvertebrate community assessment are provided, while stressing proper QA/QC. The application of the Sediment Quality Triad approach is recommended, developed to utilized three measures of sediment quality: sediment chemistry, which measures contamination; sediment bioassay, which measures toxicity; and biological community structures, which measures biological alteration.

**Project 4.7.5: Ion Speciation**
**Expenditures: $35,092**

The project objective was to provide estimates of the most probable species of a given metal, and their redistribution when raw AMD is mixed with receiving waters. Ionic speciation must be considered in the development of monitoring criteria and monitoring programs which attempt to predict the environmental impact of metals introduced into the environment. Toxicity of dissolved metals is dependant on the physical/chemical parameters associated with specific species. The model, described in the report titled "Evaluation of *B.C. Mine* for Application to Acid Mine Drainage Regulations", gives projections of metal speciation at any one point in time from a given location. Historical data on the site combined with total metal levels provide the basis for potentially using predictive modelling as part of the regulatory process. With the information provided, in terms of organic binding and free metal ion activity, it may be possible to provide increased metal into the system before biological impact is observed. In addition to this, metal metabolism of indicator organisms as a controlling system may well be an important consideration. Further development of the model *B.C. Mine* is not being pursued at this time.

**Project 4.7.6: Paleolimnology Techniques**
**Expenditures: $16,500**

The extent of an operation's environmental impact can only be determined with respect to original, baseline values. Long term studies may be necessary to establish baseline levels at existing mine sites, however cost is often a prohibiting factor. The use of paleolimnology was therefore considered for describing past conditions including, for example, pre-mining conditions, at active or closed sites. Large scale studies in North America and Europe have successfully used paleolimnological indicators for effects of acid rain and these have been reviewed to evaluate whether similar techniques could be applied to AMD monitoring. The report, based on a literature review, concludes that it should be possible but that it would first be necessary to develop a calibration data set which relates species assemblages of the chosen taxon to levels of AMD-related parameters. Currently there is no commitment to develop an

**appropriate calibration data set.**

## TECHNOLOGY TRANSFER

**Project 5.4.1: Acid Rock Drainage Technical Guide - version française**
**Expenditures: $23,700**

**The Guide is a french version of the Draft Acid Rock Drainage Technical Guide. It provides the most comprehensive and easy-to-understand overview of the issue and technical aspects of acidic drainage (2.23.1). Increase in understanding of the issue, particularly in the mining industry, is a MEND priority. One hundred copies of the french version of Draft Acid Rock Drainage Guide were printed and seminars were held in Val-d'Or and Noranda to explain the guide.**

**Project 5.5.1: Preliminary MEND Research Plan**
**Expenditures: $25,000**

**The original plan (RATS) was produced in 1988. This plan called for an expenditure of $12.5 million over 5 years. In May 1991, the MEND Management committee requested that each of the technical committees produce a revised plan for MEND. The technical committees reviewed the progress to date; examined the priorities; produced a focused plan with distinct outputs; and defined an end to the program. The Revised Research Plan for MEND includes the decisions of the MEND Board of Directors to expand the program to $18 million total expenditure and to extend the program to the end of December 1997.**

**Project 5.6.1: Second International Conference on the Abatement of Acidic Drainage**
**Expenditures: $127,000**

**The Conference was an outstanding success. Over 500 delegates from around the world attended the 3 day conference at the Sheraton Hotel in Montréal on September 16, 17 and 18, 1991. There were 134 technical papers presented in 15 different sessions. Also there were 3 days of poster sessions. Workshops were presented on September 14 and 15 and these workshops were well attended. There were field trips after the conference, to Bathurst, New Brunswick, to Noranda, Québec and to Elliot Lake, Ontario. MEND participants took the opportunity to present and listen to many of the excellent presentations, to meet many people from Canada and around the world, and to have several MEND technical committee meetings and to invite interested guests to these meetings. Many attenders commented that the conference was the best conference of any kind that they had ever attended. The proceedings (4 volumes) are available from CANMET.**

# APPENDIX C
## Recently Completed Projects

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| Number | Titles: |
|---|---|
| 1.12.1a | Compile AMD Prediction Data - DBARD |
| 1.19.1 | Kinetic Test for Cinola Gold Project |
| 1.25.1 | Development of a Soil Atmosphere Flux Model for Design of Sulphide Tailings Cover Systems - Phase I |
| 1.26.1 | Development of a Modelling Methodology for Prediction of Seepage Quality from Acid-Generating Waste Rock - Phase I |
| 1.31.1 | Study of Weathering Employing SIMS |
| 1.32.1 | Prediction and Prevention of Acid Rock Drainage - A Geological and Mineralogical Approach |
| 2.11.2a | Literature Review Report: Possible Means of Evaluating the Biological Effects of Subaqueous Disposal of Mine Tailings |
| 2.21.2 | Engineered Dry Covers for Tailings - Noranda |
| 2.23.2ab | Hydrogeological and Geochemical Analysis of the Thickened Tailings Disposal (TTD) System at Kidd Creek Mines. |
| 3.11.1d | Treatment of Acidic Seeps Employing Wetland Microbiology |
| 3.12.2 | Evaluation of Wetlands at Panel "A" Site |
| 3.13.1a | Passive Treatment of Small Seeps |
| 3.21.2a | Removal of Metals from AMD - Chemical |
| 4.2.1 | Decommissioning Criteria |
| 4.6.2 | Continuous Monitoring of AMD - Literature Review |
| 4.8.1 | Monitoring of the Flooded Solbec Pit |
| 5.1.1a-c | Provincial Workshops |
| 5.3.1 | Laurentian Database |
| 5.3.2 | Expand Databases at Laurentian & UBC |

**Project 1.12.1a:** Compile AMD Prediction Data - DBARD
**Budget:** $45,000
**Sponsors:**..............................................................................................................................................
British Columbia..............................................................................................................................$32,300
CANMET.........................................................................................$12,300
**Expenditures:** $44,600
**Contractor:** Morwijk Enterprises/University of British Columbia

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Objective:

The objective of the project was to develop an acid mine drainage database of prediction test results by developing an accessible user-friendly database program, and adding available prediction data for mine projects in B.C. initiated subsequent to 1980. The data can then be analyzed for common trends and important differences, and recommendations made for improved approaches to pre-mine prediction.

Outputs:

A computer database has been developed through Morwijk Enterprises using dBase III plus, and date-entry templates prepared into which information can be entered. A comprehensive users manual for Version 2.0 of the database has also been completed and both the manual and database are available through the Chair for Mining and the Environment at the University of British Columbia.

The Database for Acid Rock Drainage (DBARD) is currently being managed at the University of British Columbia. It contains a significant quantity of prediction and other mine component characterization data for 119 mines in British Columbia. The collection of waste rock and tailings prediction data has largely been obtained from Mine Application Submission Reports to the government. The database includes information on mines, mine component analyses, mine component metal leach tests, static tests, and kinetic tests. Data are available on over 3,000 samples, including 3062 static test results, 1061 kinetic test cycle results, and metal analyses for 756 samples. Although dBASE III plus is required to run DBARD, the database files can be accessed and manipulated using a large number of standard database and spreadsheet programs.

Recommendations:

The information input to date still only represents a small percentage of the huge quantity of ARD prediction data that have been generated over the past few years. Further data entry is therefore recommended both within and outside of British Columbia. It is also recommended that the database be made more generally available. A program to maintain and further develop the database is being proposed for 1994 (1.12.1b).

**COMPLETEDPREDICTION - Chemical Prediction**
**March, 1994**

**Project 1.19.1:** **Kinetic Test for Cinola Gold Project**
**Budget:** $100,000 Total: 1990($43.7k), 1991($26.3k), 1992/93($30k)
**Sponsors:**

|  |  |
|---|---|
| British Columbia | $25,160 |
| CANMET | $20,000 |
| City Resources | $ 2,400 |
| Environment Canada | $46,800 |

**Expenditures:** $94,360
**Contractor:** Norecol, Dames & Moore

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**Objective:**

This project involved the continuation of some of the long-term predictive testing of waste rock initiated for the Cinola Gold property in 1988 by City Resources. The objectives were specifically to:

- characterize 6 years of acid generation trends from four on-site waste rock pads;
- evaluate a column study of mixing calcareous rock with waste rock;
- characterize material that has undergone over 3 years of humidity cell weathering; and
- compare and evaluate various predictive methods used.

**Outputs:**

Some of the more advanced and long-term work in prediction of acid mine drainage has been conducted for the Cinola Gold Project (Queen Charlotte Islands, B.C.). These tests included: acid-base accounting (ABA); humidity cells to examine the long-term acid production potential of marginal material (as defined by ABA); shake flasks to test short-term acid release; column experiments to investigate the effect of limestone blending; and field waste rock piles to study the relationship between laboratory and field acid production.

Leachate from the 4 waste rock pads were monitored through 1993 and material from one pad was sampled to analyze the extent of weathering. Although little sulphide sulphur remains, the pads have not been dismantled. Of the 5 columns containing waste rock and varying percentages of limestone only the column with a Neutralization Potential/Acid Potential (NP/AP) ratio >1 generated pH-neutral water throughout the 5 year experiment. Based on

**leachate data this column was, however, also predicted to go acid. The columns were dismantled in late 1993.**

**Recommendations:**

**The report, to be available in 1994, will contain a summary of all test results and leachate data and an assessment of the methods used. No additional monitoring of the Cinola test materials is proposed at this time. The ability to correlate laboratory predictive test results to field conditions should however be considered further.**

**Project 1.25.1:** Development of a Soil Atmosphere Flux Model for Design of Sulphide Tailings Cover Systems - Phase I

**Budget:** $49,500

**Sponsor:** ......................................................................................................................................
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..................................................................................................CANMET
...................................................................................................$55,800

**Expenditures:** $55,800

**Contractor:** University of Saskatchewan

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Objective:

Based on routine climate data and soil properties, the objective of this project was to develop a program for the computation of moisture fluxes between tailings, cover systems and the atmosphere.

Outputs:

Carefully designed soil cover systems may be used as oxygen barriers in the control of acid mine drainage, the success of which will depend on climatic conditions and cover system properties. The development of a tailings-cover-atmosphere flux model enhances the ability to optimize the design of such cover systems. A mechanistic model for evaluating the flux boundary conditions and the soil-atmosphere interface, developed at the Universities of Manitoba and Saskatchewan, has been used.

The mathematical derivation and formulation of the finite element solution for coupled heat and mass transfer in soil covers has been successfully completed at the University of Saskatchewan. The Soil Atmosphere Flux model is currently running on PC/DOS computers. The program has been tested by comparing its solution with those computed by other well established methods. A preliminary version of the program and user's manual was completed in mid 1993 which was further tested and modified. A final version of both the software and manual have been received and will be available in 1994.

Recommendations:

The University of Saskatchewan will continue with the development of the model to accommodate water flow and hydraulic effects under freezing conditions. Field data for this

**work will be collected from a mine site in British Columbia.**

COMPLETEDPREDICTION - Modelling
March 1994

**Project 1.26.1:** Development of a Modelling Methodology for Prediction of Seepage Quality from Acid-Generating Waste Rock - Phase I

**Budget:** $90,000

**Sponsors:**

British Columbia ....................$60,000

Environment Canada ....................$30,000

**Expenditures:** $90,000

**Contractor:** Steffen Robertson & Kirsten

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## Objectives:

To develop a preliminary model based on the current state-of-the-art for predicting drainage water quality from waste rock dumps using existing theoretical and empirical relationships, and to determine the level to which a waste rock model can be developed to predict numerical values for the water chemistry of drainage from waste rock piles.

## Outputs:

The primary objective of the applied modelling methodology is to simulate the concentrations of contaminants in the water draining from mine rock. This involves all processes from the infiltration of uncontaminated water into the pile, through to the measured impact downstream. The report separates these processes into 10 component models: 1) pile geometry; 2) geochemical characteristics; 3) physical characteristics; 4) hydrogeological; 5) temperature; 6) oxygen (pore gas); 7) pile water quality; 8) pile base mixing; 9) groundwater plume; and 10) downstream water quality. For each of these components a description of the significance, current understanding, and recommended development is described.

The report recommends that first priority be given to further development in areas 2,3,4 and 7, with the geochemical characteristics being given highest priority.

The recommended developments addressed specifically by the proponents involved site assessment, mathematical simulation of rock pile construction, hydrological/hydrogeological modelling and specific humidity cells.

**Recommendations:**

**The report recommends that effective development of the proposed 'applied modelling methodology' is currently the only viable basis for prediction, thus allowing for practical decision making regarding ARD impact and control.**

**COMPLETEDPREDICTION - Basic Research**
**March 1994**

| | | |
|---|---|---|
| **Project 1.31.1:** | **Study of Weathering Employing SIMS** | |
| **Budget:** | **$95,000** | |
| **Sponsors:** | **Echo Bay** | **$ 5,000** |
| | **Ontario** | **$53,500** |
| | **DIAND** | **$18,000** |
| | **INCO** | **$21,100** |
| **Expenditures:** | **$98,600** | |
| **Contractor:** | **Klohn Leonoff/University of Western Ontario** | |

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**Objective:**

The main project objective was to assess the applicability of Secondary Ion Mass Spectrometry (SIMS) and related surface methods in the prediction of acidic drainage in weathered and non-weathered mine tailings and waste rock.

**Outputs:**

A parallel program involving surface analytical assessment of weathered and unweathered material, and conventional ARD prediction column tests was carried out. Originally, naturally and artificially weathered surfaces were to have been analyzed using Secondary Ion Mass Spectrometry (SIMS) to determine the predictive capacity of different humidity cell leaching regimes. This direct comparison was not possible. The sulphide mineral size and content in the tailings (~3.0% S) and waste rock (~0.5% S) samples employed proved to be insufficient for the application of SIMS. A minimum surface area of about 50 microns diameter is required for best results. Attempts to concentrate the sulphides using non-destructive means was unsuccessful.

Surface-sensitive analyses were broadened to include Auger Electron Spectroscopy (AES) and X-ray Photoelectron Spectroscopy (XPS), and have focused on pure pyrrhotite and arsenopyrite minerals. For these materials, depth of the oxidation zone was limited through controlled exposure to oxidants to allow identification of the alteration zones. Advantages and disadvantages of the three surface analytical techniques are presented.

Static and kinetic tests as well as whole rock, elemental and petrographic analyses were carried

**out on tailings from Echo Bay's Lupin Mine in the Northwest Territories and on waste rock obtained from Inco's Thompson Mine in northern Manitoba. With respect to the humidity cell protocol, varying chemical leachates were substituted for deionized water in the 30 week program.**

**Recommendations:**

**Although direct comparison of naturally and artificially weathered material to assess predictive tests was not addressed, such a comparison may warrant further attention.**

**COMPLETEDPREDICTION - Basic Research**
**March 1994**

**Project 1.32.1:** **Prediction and Prevention of Acid Rock Drainage - A Geological and Mineralogical Approach**

**Budget:** $73,000

**Sponsors:**

| | |
|---|---|
| BHP Minerals | $ 3,230 |
| Cominco | $ 3,230 |
| Environment Canada | $55,000 |
| Homestake Canada | $ 3,230 |
| HBM&S | $ 3,230 |
| Placer Dome | $ 3,230 |
| Teck | $ 3,230 |

**Expenditures:** $73,000

**Contractor:** National Hydrology Research Institute

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**Objective:**

The three main objectives of this project were to determine the tendency of major types of metallic sulphide deposits to generate acid, the relative oxidation rates of individual sulphide species in polysulphide assemblages, and the initial field measurements and laboratory analyses needed to asses the acid generation potential and expedite environmental impact assessment.

**Outputs:**

Based on a literature survey and supplementary field investigations, seven common types of metallic mineral deposits occurring in western Canada are ranked according to the potential for development of acid rock drainage (ARD). The deposit susceptibility is based largely on the net acid-generating potential of the prevalent mineral assemblages, the accessibility of the reacting minerals to weathering agents, and potential mediation by iron-oxidizing bacteria. A formula for assessing acid rock drainage potential based on field estimates of mineral abundance is suggested in the report.

To determine the relative weatherability of common sulphide minerals, a kinetic-type weathering experiment using polished thin sections was conducted. Detailed examination of the prevalent sulphides indicate the importance of trace element composition in affecting the stability of individual sulphides. It is therefore suggested that a general weathering sequence for the common sulphides may not exist except on a local scale.

**Recommendations:**

The report recommends that field geologists be trained to collect and interpret mineralogical and geological data and be involved in acid rock drainage assessment at every stage of a mining project. The report suggests a practical checklist for field assessment of ARD potential during mineral exploration and tasks at various phases of a pre-mine development are briefly discussed.

**COMPLETEDP&C - Underwater Disposal**
**March 1994**

**Project 2.11.2a:** **Literature Review Report: Possible Means of Evaluating the Biological Effects of Subaqueous Disposal of Mine Tailings**
**Budget:** $16,300
**Sponsors:**
Placer Dome ....................................................................................................$16,300
**Expenditures:** $16,300
**Contractors:** The Rawson Academy of Aquatic Science
INRS - Eau

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**Objectives:**

In 1992 the Rawson Academy undertook a critical review of the studies conducted to 1991 on the subaqueous disposal of mine tailings under the MEND Program. In its final report, the Scientific Review Team recommended that "selective and additional literature reviews" be undertaken on the biological uptake of metals, their bioaccumulation, and their possible toxic effects on aquatic organisms. The literature review aims to respond to this recommendation.

**Outputs:**

Given the extensive literature available on metal-organism interaction and the consequent need to limit the scope of the review, the focus was on the possible biological effects of subaqueous disposal of mine tailings. The basic premise has been that mine tailings and their constituent metals, may affect aquatic life in two ways: indirectly (i.e. by leaching of the metals into the ambient water, followed by their assimilation from the aqueous state), and directly (e.g. in macrofauna, by ingestion of the tailings and assimilation of the metals). Both routes of metal exposure were considered in this literature review.

The metals of concern were those that are commonly present in reactive mine tailings, are recognized as potentially toxic at low concentrations to aquatic biota, and that exist in natural waters as dissolved cations (e.g. Cd, Cu, Ni, Pb, Zn). Anionic species such as arsenate/arsenite, or organometallic species such as methyl-mercury were not investigated.

The final report is available from CANMET.

**Recommendation:**

**This review identifies promising geochemical and ecotoxicological approaches that might be used to monitor the biological effects of the subaqueous disposal of reactive mine tailings. No further review of the literature is planned at this time.**

**Project 2.21.2:** **Engineered Dry Covers for Tailings - Noranda**
**Budget:** **$469,000**
**Sponsors:** ..........................................................................................
.......................................................................................... **Noranda**
..........................................................................................**$219,700**
**CANMET**..........................................................................**$161,000**
**Québec** ..........................................................................**$152,100**
**Expenditures:** **$532,800**
**Contractors:** **Noranda Technology Centre (NTC)**
**McGill University/École Polytechnique**

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**Objective:**

**The objective of the project was to design, construct and evaluate the effectiveness of engineered soil covers in preventing and controlling acid generation in reactive mine tailings. The evaluation consisted of performance monitoring of field test plots at the decommissioned Waite Amulet tailings impoundment near Rouyn-Noranda, Québec and laboratory experiments at NTC.**

**Outputs:**

**A total of four test plots, consisting of two composite soil covers with a compacted clay layer sandwiched between a fine and a coarse sand layer, one geomembrane cover and a control (tailings without cover) were constructed and instrumented to measure gaseous oxygen concentrations, water content, suction, temperature and pore water quality at various depth. In addition, a collection basin lysimeter, initially filled with unoxidized tailings, was installed below each cover to measure both the quantity and quality of percolated water. The soil cover was placed in a high water saturation condition and close to maximum compaction density to ensure a reasonably low hydraulic conductivity that would reduce infiltration in the cover.**

**Six columns were installed in the laboratory to simulate soil-covered and uncovered tailings. The columns were subjected to cyclic wetting and drying, at laboratory temperature. Gaseous oxygen concentrations, water content, temperature and drainage water quality were measured over time. Results of the laboratory, field and modelling studies indicated that the oxygen flux is reduced by 91 to 99% by the soil cover. Monitoring of acid fluxes over time suggested that the rate of acid production decreases with time. Hydrologic modelling indicated that water percolation through the cover is about 4% of precipitation. Field lysimeter data gave 6% or 54 mm per year which indicates a reduction of 80% in the total annual infiltration into the**

**uncovered tailings. The effects of freeze-thaw on the integrity of the compacted clay layer showed that freezing and thawing have not adversely affected the cover. The final report, in two volumes, will be available from CANMET in early 1994.**

Recommendation:

**Many recommendations for additional work were identified in the final report including the preparation of a set of design and construction protocols for soil covers for use by others and the effects of root penetration. The P&C committee recommends that prior to additional work being carried out, a peer review on the work to date should be completed in 1994.**

COMPLETEDP&C - Others
March 1994

**Project 2.23.2ab:** Hydrogeological and Geochemical Analysis of the Thickened Tailings Disposal (TTD) System at Kidd Creek Mines.
**Budget:** a: $60,000 b: $88,700
**Sponsor:** ..........................................................................................
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..........................................................................................Falconbridge
..........................................................................................$155,700
**Expenditures:** $155,700
**Contractor:** Noranda Technology Centre (NTC)

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## Objectives:

The objective of this two-year study was to measure the hydraulic properties of the TTD tailings site to analyze their effects on the long-term impacts to the environment.

## Outputs:

The Robinsky designed TTD system used at Kidd Creek has the potential to reduce acid generation and seepage by creating a homogeneous tailings mass of low hydraulic conductivity and high moisture retention characteristics in which oxygen entry and resulting tailings oxidation are limited.

NTC carried out a field evaluation of the principal components of the site hydrology to obtain a verification of the high moisture retention of the TTD deposit. The field program included measurements of moisture content, hydraulic head, water table elevation, and hydraulic conductivity. Precipitation, pan evaporation and evaporation from tailings were monitored during 1991-1992 and a monthly water balance was prepared. Porewater was sampled and analyzed for major metal and ion concentrations. The result of the study from measured physical characteristics such as tailings grain size and porosity, inferred the presence of a significant capillary fringe, or tension-saturated zone above the water table.

The analysis of porewater indicates that sulphide oxidation is occurring within the tailings mass. Considering the tailings cone at present, then following closure, tailings saturation and water table position are expected to resemble that observed in areas of the cone where deposition is not active. Release of contaminants from the tailings to the environment should remain at present rates because porewater velocities are low because of the sustained near-surface saturated conditions. The final report is available from CANMET.

**Recommendation:**

**The study suggested that the TTD method seems to be advantageous because of the low dissolved metal fluxes to the environment. At the completion of the tracer (2.23.2c) and the geochemical (2.23.2d) studies, it is recommended that a synopsis report assessing the effectiveness of the thickened tailings disposal option be completed.**

March 1994

**Project 3.11.1d:** Treatment of Acidic Seeps Employing Wetland Microbiology (ARUM)
**Budget:** $80,000
**Sponsors:**

| | |
|---|---|
| Environment Canada | $20,000 |
| CANMET | $20,000 |
| INCO | $20,000 |
| Québec | $20,000 |

**Expenditures:** $80,000
**Contractor:** Boojum Research

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**Objectives:**

The objective for the final year (phase d) of this study was to complete the field work, determine the design parameters for the ARUM system and to evaluate its applicability.

**Outputs:**

The final report entitled: "Treatment of Acidic Seepages Using Wetland Ecology and Microbiology: Overall Program Assessment" summarizes the field observations and measurements over 4 years in the field, determines the operating parameters for the ARUM system; produces design criteria and conceptual design, and estimates operating costs. The results show that some very good water quality results had been achieved at flow rate of 1 litre/minute. However, is appears that the system is not designed for final treatment of large flows, but rather is applicable for pre-treatment before an engineered treatment system. This will reduce costs by generating alkalinity and by precipitation of some of the metals. It could also be used for small seeps, or part of a package involving dry covers to reduce effluent flow rates.

**Recommendations:**

Considerable research and process development have been done on passive systems for treatment of AMD. The studies, including the ARUM process, have demonstrated that the use of passive systems to treat acidic seepages is technically feasible but that the performance and the applicability of these systems remain uncertain. Several process-limiting factors, such as temperature, flow rates, and rates of addition of bacteria nutrients, were identified during

**these studies. MEND has decided to conduct a summary review of passive treatment systems, including the ARUM process. This review will include the identification of critical design criteria and operating parameters, an estimate of costs for treatment of AMD using passive systems, and make recommendations on their applicability in Canada.**

**Project 3.12.2:** Evaluation of Wetlands at Panel "A" Site
**Budget:** $45,000
**Sponsors:**..........................................................................................
..........................................................................................
..........................................................................................CANMET
..........................................................................................$22,500
Ontario..........................................................................................$22,500
**Expenditures:** $45,000
**Contractor:** CANMET - Elliot Lake Laboratories

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**Objective:**

The objective of this study was to establish if an existing natural wetland at Elliot Lake provides significant treatment and control over water quality parameters associated with the oxidation of pyritic tailings and migration of contaminants.

**Outputs:**

A final report entitled: "Panel Wetlands: A Case History of Partially Submerged Pyritic Uranium Tailings Under Water" is available. The report provides detailed information on surface and ground water hydrology, chemistry, water balance and their seasonal variations, solid phase characteristics of sediment/substrate, bacterial enumeration and vegetation uptake of metals in the basin.

A preliminary water quality survey in 1989 had revealed an improvement in pH from 3.6 to 6.6 and electrical conductance "Ec" from 1100 to 260 µS, as the water moved from the exposed western section to the submerged eastern area. In the summer and fall of following years, water quality parameters were respectively pH 4.4 to 8.1, and Ec 185 to 1271. This large site supports a very healthy, dense and self-sustaining vegetation consisting of cattails and filamentous moss with an organic layer 15cm in height, on top of unoxidized tailings slimes.

The survey results have confirmed that the wetland/water cover system in the Panel wetlands basin is effectively controlling the acidic drainage from partially submerged pyritic uranium tailings. It is concluded that the system would continue to function as long as the water cover is maintained and its performance could be further improved if all the tailings were completely submerged.

**Recommendations:**

**This study shows that shallow water covers in combination with a natural wetland have potential to permit "walk-away". In its proposed review of passive systems for treatment of AMD, MEND will investigate further the applicability of wetland systems.**

COMPLETED

TREATMENT
March 1994

**Project 3.13.1a:** **Passive Treatment of Small Seeps**
**Budget:** $90,000
**Sponsors:**..........................................................................................................
..........................................................................................................
.......................................................................................... Noranda
..........................................................................................$60,000
CANMET..............................................................................$30,000
**Expenditures:** $90,000
**Contractor:** Noranda Technology Centre

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**Objective:**

To evaluate and demonstrate the applicability of various passive, low-cost processes for treating small volumes of acidic seepage.

**Outputs:**

Passive treatment processes are under development in Canada and the United States and these include anoxic limestone trenches, lime organic beds, biotrenches, and biosorbents. Bench-scale treatment tests were carried out at Noranda Technology Centre in 1992 to evaluate 4 passive treatment methods. Process parameters such as pH, acidity, Eh, metal & sulphate concentrations, flow rates and hydraulic characteristics were determined.

The results suggest that the best system for pH increase and metals removal can be obtained by using combinations of lime-organic mixtures and anoxic limestone trenches, and biosorbents and limestone systems. The final report will be available in early 1994.

**Recommendations:**

Although the work completed has shown some positive results, certain concerns would have to be addressed before moving to field work. Further work would be necessary in some areas, including an economic evaluation of methods, investigation of metal removing processes and temperature effects on the efficiency of each method, and performance at low temperature (0-4°C). For these reasons, the Treatment committee recommended not to proceed with a field test. However, these questions are difficult to address by further bench tests due to the time required and different conditions encountered in the laboratory and the field. In its proposed review of passive systems for treatment of AMD, MEND participants will address the question

**of applicability of these systems in Canada.**

**Project 3.21.2a:** Removal of Metals from AMD - Chemical Treatment
**Budget:** $100,000
**Sponsor:** ..........................................................................................................................................
..........................................................................................................................................
.................................................................................................................................. Noranda
..................................................................................................................................$90,000
**Expenditures:** $90,000
**Contractor:** McGill University
Noranda Technology Centre

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**Objectives:**

To develop and evaluate selective precipitation techniques for separation of toxic metals from typical acid mine drainage.

**Outputs:**

Several chemical methods were evaluated to selectively precipitate and recover metal ions from AMD. A conceptual flowsheet consisting of a three-step precipitation process was developed. The process consisted of oxidizing ferrous to ferric ion with $H_2O_2$ and precipitating ferric hydroxide sludge in the first step, recovering/recycling Zn and Cu as sulphide precipitates in the second step and, in the third step, removing residual metal ions remaining in the water via lime neutralization to obtain a final water quality in compliance with the regulated standards.

Further bench scale investigations have been carried out to optimize the initial flowsheet of separating iron as the hydroxide using lime and a dodecylamine surfactant, DDA, which could reduce coprecipitation of other metal ions. Copper and zinc have been removed as the sulphide, and techniques have been tried to produce a precipitate that can be recycled to the zinc production circuit.

The results show that more than 90% zinc recovery and greater that 50% Zn grade can be obtained with the three-step method. A preliminary economic analysis was conducted to compare the various options in terms of available reagents for precipitation and methods of oxidation. Based on the preliminary economic analysis, the feasibility of the proposed value recovery process would be dependent on the costs associated with chemical reagents and solid/liquid separation. The final report will be available in early 1994.

**Recommendations:**

Although this study shows positive results, the proposed approach poses economical and technical constraints preventing its further development unless there are new concepts which will radically reduce chemical reagent costs and solid/liquid separation steps. For this reason, it is not recommended to do a pilot test of this process.

**Project 4.2.1:** Decommissioning Criteria
**Budget:** $15,000
**Sponsor:** ........................................................................................................................
........................................................................................................................
........................................................................................................................Ontario
........................................................................................................................$5,000
Homestake Canada ..........................................................................................$5,000
HBM&S ...........................................................................................................$5,000
**Expenditures:** $15,000
**Contractor:** Jacques Whitford Consulting Engineers

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**Objective:**

The objective of the project was to review Canadian and United States legislation relevant to decommissioning acid mine drainage sites. The purpose of the review was to provide government agencies, industrial representatives and other organizations and individuals with an overview of the existing Canadian and United States regulatory framework relevant to decommissioning AMD sites and to summarize the criteria used by Canadian and United States regulatory agencies to assess the performance of a decommissioning AMD site.

**Outputs:**

In general, regulatory strategies specific to decommissioning AMD sites are still in the development stage, both in Canada and the United States. The criteria that would typically be used in assessing a site are effluent quality leaving the mine site, groundwater and surface water quality downgradient. Effluent limitations, drinking water standards, and surface water quality criteria have all been developed at a federal level by the United States EPA. In Canada, non-enforceable water quality guidelines or objectives are prevalent, with enforceable site specific parameters incorporated into mine operation permits or licences.

Apart from the federal guidelines, those of the provinces and territories in Canada were also covered, while for the United States, the review concentrated on the following seven states: Idaho, Nevada, California, Montana, Colorado, Pennsylvania and West Virginia.

**Recommendations:**

The available report is intended as a summary document. Many acts, regulations and

**guidance documents are referenced throughout, however for complete details in a specific area the reader has been encouraged to refer to the reference directly or to contact the appropriate regulatory agency. A partial listing of these agencies in the United States and Canada is included.**

COMPLETED

MONITORING
March 1994

**Project 4.6.2:** Continuous Monitoring of AMD - Literature Review
**Budget:** $50,000
**Sponsor:** ........................................................................................................................
........................................................................................................................
......................................................................................................Québec
......................................................................................................$50,000
**Expenditures:** $50,000
**Contractor:** University of Laval

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Objective:

The objectives were to identify and evaluate the capability of commercially available continuous monitoring technologies to address the monitoring requirements of AMD sites in Canada, and to identify the advantages and disadvantages of continuous monitoring.

Outputs:

For pre-operational to post-decommissioning stages of a mine site, sampling programs can be developed for all three phases, liquid, solid, and gaseous. Sampling of the liquid phase to assess environmental impact is most common and was targeted in this project. Based to some extent on regulations and guidelines governing liquid effluent quality, criteria were developed to evaluate currently available continuous monitoring technologies and their applicability to AMD. Criteria included resistance to extreme temperatures, precision, autonomous operation, minimum calibration requirements, and the resolution of interference problems.

An international survey of commercially available monitoring equipment (selective ions, redox potential, dissolved oxygen, pH, electrical conductance, etc.) applicable to AMD resulted in a list of just over 50 manufacturers. The identified equipment was divided into three categories: physical parameters (pH, dissolved oxygen, temperature etc.); chemical concentrations (Cu, Fe, As ions etc.); and meteorologic conditions (precipitation, wind etc.).

The evaluations and appended information focused upon integrated commercially available continuous monitoring instruments. Five systems were identified which addressed the physical parameters while only two of these also monitored selected ion concentrations. One system, PIRANA, was recommended as most applicable. Actual expected detection limits, precision, maintenance requirements and cost, were not addressed for AMD specifically and may be expected to vary considerably between sites.

**Recommendations:**

**The concept of detailed data collection at an AMD site over a finite period to assess trends and potential correlations is considered worthwhile in the development of a focused, long term monitoring program. However, the specific application of the PIRANA system, as recommended in the report, is not being considered at this time.**

COMPLETED

MONITORING
March 1994

**Project 4.8.1:** Monitoring of the Flooded Solbec Pit
**Budget:** $139,000
**Sponsor:** ......................................................................................................................................
.......................................................................................................................................................
.......................................................................................................................................CANMET
.........................................................................................................................................$ 30,000
Québec ..................................................................................$109,000
**Expenditures:** $139,000
**Contractor:** Serrener Consultation Inc.

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**Objective:**

The objective of the three-year monitoring project was to assess the long-term effects of relocating waste rock into an open pit and subsequently flooding the pit for the control of acid generation.

**Outputs:**

The Solbec mine is located in the Eastern Townships in the province of Québec. Acid generation and drainage from waste rock on surface resulted in the contamination of surface water and high concentrations of base metals. In 1988, 276,000 cubic meters of highly oxidized waste rock were placed in the dewatered pit, covered with a 5 cm layer of limestone and reflooded to a water depth of 1.5 m as part of a control measure. Characterization of the pit followed by a detailed monitoring program has been undertaken to better understand the consequences of the chosen method of control on the surrounding environment.

In the first year, the work included: mine site characterization; borehole placement (one upstream, two within the pit and two downstream); piezometer installation in the boreholes (the four latter, multilevel, the former, single level); and chemical analyses of solid and liquid samples from the pit and surrounding areas. The general hydrogeological regime for the site was prepared using all information available.

Based on first year results, it was been recommended that additional boreholes be placed downstream of the filled and flooded pit to allow more comprehensive monitoring of potential downstream contaminant migration. A geophysical survey was carried out in early 1993 to optimize placement using EM-31 and EM-34. The survey results were not conclusive due to a number of interferences, but indicated a downgradient profile of contaminant from the pit.

**Recommendations:**

**The monitoring of the Solbec pit has been suspended. A review of the results and conclusions by the Prevention & Control committee may result in additional monitoring in future.**

COMPLETEDTECHNOLOGY TRANSFER
March 1994

**Project 5.1.1a-c:** **Provincial Workshops**
**Budget:** **$56,000**
**Sponsors:**..........................................................................................................
..........................................................................................................
..........................................................................................................**Ontario**
..........................................................................................................**$ 9,300**
**CRM**..................................................................................................**$20,000**
**Expenditures:** **$29,300**
**Contractors:** **MNDM, CRM, and UBC**

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**During the fall of 1993 three workshops were held by MENDO, NEDEM-Québec and the B.C AMD Task Force. These technical sessions were well attended, demonstrating the strong continuing interest in the control of AMD by industry and government.**

MEND Ontario (Sudbury, Ontario):

**About 200 delegates attended a 2-day workshop sponsored by MEND Ontario and organized through the Ontario Ministry of Northern Development and Mines. All presentations dealt explicitly with acid mine drainage. Field trips were organized to visited tailings management sites near Sudbury, Timmins, and Elliot Lake.**

NEDEM-Québec (Val-d'Or, Québec):

**Over 120 delegates participated in the "Deuxičme Colloque NEDEM-Québec" organized by the Centre de recherches minérales (CRM) and l'Association Miničre du Québec (AMQ). The workshop featured overviews of the MEND national program in the areas of prediction, prevention & control, treatment, and monitoring as well as project specific presentations on AMD research being carried out in Québec. The workshop concluded with a round table discussion on regulatory requirements for mine site reclamation in Québec.**

BC AMD Task Force (Vancouver, British Columbia):

**The second annual British Columbia Acid Mine Drainage Symposium, organized jointly by the B.C. Ministry of Energy, Mines and Petroleum Resources (MEMPR) and the University of British Columbia Chair for Mining and the Environment, attracted nearly 150 delegates from industry, the consulting community, universities and government. Papers were presented from across Canada and the United States to provide a balanced technical program. The program concluded with an informative session on the second round of "New Ideas" projects solicited by**

**MEND National.**

**Recommendation:**

**The workshops were very useful in providing technology transfer and also allowed excellent networking. Additional workshop should be supported in the future to continue ensuring effective technology transfer.**

COMPLETEDTECHNOLOGY TRANSFER
March 1994

**Project 5.3.1:** Laurentian Database
**Budget:** $35,000
**Sponsor:** ..........................................................................................................................
..........................................................................................................................
..........................................................................................................Ontario
..........................................................................................................$35,000
**Expenditures:** $35,000
**Contractor:** Laurentian University

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**Objective:**

Establish a bilingual database of materials supporting research into the control of acid mine drainage.

**Outputs:**

A bilingual database was established as part of Laurentian University's Mining Environment Database. To date there are over 9,000 abstracted references to journal articles, books, government reports, and conference proceedings.

The database includes a complete bibliographic description of titles as well as abstracts. In addition, actual documents are available from the Laurentian Library for consultation or for borrowing through interlibrary loan. Access to the Laurentian database is free to anyone with a telephone modem/computer hookup.

A brochure entitled "Mining Environment Database:Abandoned Mines, Acid Mine Drainage & Land Reclamation" has been published.

**Recommendations:**

A central source of information on acid mine drainage now exists and is a benefit to MEND membership as well as others working in this field. In order to meet MEND's objectives, the database has to be updated on a regular basis and requires continuous advertizing.

**Project 5.3.2:** Expand the Database at Laurentian University
**Budget:** $40,000
**Sponsors:**............................................................................................................................
..................................................................................................................
..................................................................................................................Ontario
..................................................................................................................$11,750
**Expenditures:** $11,750
**Contractors:** Laurentian University

---

**Objective:**

To maintain, update and provide wide access to a database on acidic drainage.

**Status:**

The information base established at Laurentian University (projet 5.3.1) will continue to expand during the MEND program. The database has to be updated on regular basis and better promotion is required to meet MENDs objectives.

The Laurentian database is primarily an information base with over 9,000 abstracted references and original documents on acid mine drainage and mine reclamation.

In 1993, two part-time graduate students were hired to enter and abstract new material received and to approach more firms and individuals for material that is not available commercially.

Laurentian University recently received requests from Australia, South Africa, Japan, and England for the PC based product. Free access is available through INTERNET for all interested researchers.

To increase the use of this database for people without on-line access, the Database is now available for sale on diskettes.

**Recommendation:**

The Laurentian Database is recognized more and more as a central source of updated information on acid mine drainage which is beneficial for MEND members. To increase its

**utilization, continuous advertizing is required.**

# APPENDIX D

## Active Projects

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| Number | Titles: |
|---|---|
| 1.14.2 | Monitoring & Modelling AMD from Waste Rock: Mine Doyon Phase II |
| 1.15.2 | AMD from Open Pits - Expansion and Verification of MINEWALL 2.0 |
| 1.22.1 | ANSTO Model at Heath Steele |
| 1.31.2 | Residual Weathering Products in Waste Rock Dumps |
| 1.32.2 | Pyrite Oxidation - Lithological and Mineralogical Approach |
| 1.41.2 | ARD Waste Rock Monitoring Database |
| 1.42.1 | Critical Review of Geochemical Modelling |
| 1.51.1 | Quantitative Analyses of Chemical and Biological Kinetics |
| 1.51.2 | Nonlinear Modelling of Chemical Kinetics for Acid Mine Drainage |
| 2.11.3ab | Evaluation of Underwater Disposal Site - Anderson Lake |
| 2.11.4a | Evaluation of Underwater Disposal Site - Buttle Lake |
| 2.13.1 | Flooding of Existing Tailings Sites - Quirke Lake |
| 2.13.2a | Flooding of Existing Tailings Sites - Solbec Cupra |
| 2.15.1 | A Study on Water Covers for the Decommissioning of Mine Waste Disposal Sites |
| 2.20.1 | Evaluation of Alternate Dry Covers for the Prevention of Acid Mine Drainage from Tailings |
| 2.22.2 | Evaluation of Dry Covers Built from Mine Tailings |
| 2.23.2c | A Tracer Study of Fluid and Contaminant Movement in the Upper Surface of the Thickened Tailings Disposal (TTD) System at Kidd Creek Mines |
| 2.23.2d | Geochemical Evaluation of the Thickened Tailings Disposal (TTD) System at Kidd Creek Mines |
| 2.23.3 | Porous Envelope Surround Disposal Method - Falconbridge |
| 2.25.1 | Reclamation of Sulphide Tailings Using Municipal Solid Waste Compost |
| 2.25.2 | Design of an Organic Barrier Using Wood Waste - East Sullivan |
| 2.31.1b | Dry Covers on Waste Rock - Heath Steele |
| 2.32.3a | Injection of Mine Tailings into a Waste Rock Pile as a Method to Control AMD - Literature Review |
| 2.34.1 | Use of Cementitious Covers to Control Acid Generation at Westmin's HW Mine - Shotcrete Field Trial |
| 2.35.2 | Lysimeter Evaluations of Cover Alternatives - Noranda |
| 2.42.1 | Development of Synthetic Polymers - Laurentian |
| 2.45.1a | Separation of Sulphides from Mill Tailings |
| 3.21.1b | Removal of Metals from AMD - Ion Exchange |
| 3.22.1 | AMD - Water Quality Survey |
| 3.31 | Use of Lime Sludges for Capping |

Continued...

## Active Projects - Continued...

| Number | Titles: |
|---|---|
| 3.32.1 | Lime Treatment - Process and Sludges |
| 4.3.2 | Reference materials |
| 4.5.1 | Field Methods Manual - Waste Rock |
| 4.5.3 | ARD Technical Guide Revision - Monitoring Section |
| 4.6.1 | Assessment of Geophysical Monitoring Methods |
| 4.6.3 | Remote Monitoring Techniques - Review |
| 4.6.4 | Piezocone Field Test |
| 4.8.2 | Sediment Sampling Probe Field Application |
| 5.2.1a-c | Communications Plan - CIMM Lectures, Brochure, TV Series |
| 5.6.2 | Third International Conference on Abatement of Acidic Drainage |
| 5.7.1 | MEND Newsletter |
| 5.8.1 | Economic Evaluation of MEND-developed Technology |
| 6.1 | New Ideas Solicitation - Round 1 |

ACTIVE

PREDICTION - Modelling
March 1994

**Project 1.14.2:** **Monitoring & Modelling AMD from Waste Rock: Mine Doyon Phase II**
**Budget:** $450,000
**Sponsors:**

| | |
|---|---|
| Cambior | $ 75,000 |
| CANMET | $150,000 |
| Québec | $150,000 |
| Lac Minerals | $ 75,000 |

**Expenditures:** $350,800
**Manager:** A. Paquet, CRM
**Contractor:** Laval University

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**Objectives:**

- Continue collection of baseline data; physical, chemical and bacteriological field measurements, chemical analyses, and meteorological data initiated in Phase I.
- Develop a waste rock alteration indicator for determining the extent of oxidation.
- Determine the rate of AMD generation and predict long-term behaviour as a function of potential control measures.

**Status:**

The south dump at Mine Doyon has afforded an excellent opportunity to study a waste rock dump in detail. Phase I (1.14.1) resulted in the instrumentation and detailed characterization of the south waste rock dump, as well as long-term prediction of acid generation potential using two independent methods. Phase II continues and has augmented the monitoring program initiated in Phase I. From the information collected, geochemical, physical and hydrologic simulation capabilities are being developed. The project is expected to be completed in early 1994.

Geochemical characterization and modelling is concentrating on the comparison of AMD compositions along a typical flowpath from the dump surface through the unsaturated zone, saturated zone, and collection ditches. The dump is a major reservoir of acidity and the storage has been estimated in relation to annual discharge. A principle objective is to develop a mineralogical index to describe and characterize mineral transformations in acid producing waste rock dumps.

Thermal gradients and air convection models predict maximum oxidation activity near surface. Physical modelling of heat transfer as related to diffusive transport is completed and transient conditions involving air convection, water vapour transport and heat production is in progress.

Use of meteorologic and hydrologic data collected at the site has enabled a water balance to be established. Average residence times along different paths from dump surface to drainage ditches have also been estimated. Evaporation losses in the strong convecting system will be evaluated.

| | | |
|---|---|---|
| Project 1.15.2: | AMD from Open Pits - Expansion and Verification of MINEWALL 2.0 | |
| Budget: | $88,000 | |
| Sponsors: | | |
| | | CANMET |
| | | $26,500 |
| | British Columbia | $26,500 |
| | BHP Minerals | $14,600 |
| | Noranda | $20,060 |
| Expenditures: | $38,300 | |
| Manager: | C. Weatherell, CANMET | |
| Contractor: | Morwijk Enterprises Ltd. | |

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**Objective:**

**This project addresses two primary objectives: expansion, improvement, and verification of the original MINEWALL code from version 1.0 to 2.0 with appropriate user instructions; and the collection of field data at two representative minesites and the subsequent calibration of MINEWALL Version 2.0 using this field data.**

**Status:**

**In 1990, a literature review on the physical and geochemical impacts of mines, a short-term field investigation at Equity Silver, B.C., and the preliminary development of the program MINEWALL to simulate effluent quality from open pits were completed (project 1.15.1). The above literature review has been updated to the end of 1993. The known limitations of the model code such as the arbitrary equations describing pit flooding and decreasing sulphide oxidation through time, and the inability to explicitly simulate effluent quality from underground mine walls are also being addressed. Version 2.0 has been written as several individual, updatable modules and most of the programming effort to date has focused on data entry.**

**The collection of field data is in progress at the Island Copper and Bell Mine open pits in British Columbia. Washings from the wall stations installed on various sections of the two open pit walls will continue to be collected as long as the stations remain unfrozen.**

**Generation of a users manual will be done on completion of the coding, testing and verification of Version 2.0 of the program. Verification will consist of mathematically comparing MINEWALL predictions against known outcomes using simplified data sets. To date, each existing module has already been tested with simplified data sets. More extensive datasets, and finally, real data will be used in future.**

**A detailed user's manual with explanations of procedures for input, editing, and output, as well as instructions for collecting field data and calibrating MINEWALL version 2.0 to field data is expected to be complete by mid 1994.**

ACTIVE

PREDICTION - Modelling
March 1994

**Project 1.22.1:** ANSTO Model at Heath Steele
**Budget:** $145,000
**Sponsor:** ........................................................................................................................
........................................................................................................................
........................................................................................................................CANMET
........................................................................................................................$85,000
New Brunswick ........................................................................$25,000
Noranda ..................................................................................$65,000
**Expenditure:** $90,000
**Manager:** E. Yanful, Noranda
**Contractor:** Nolan Davis & Associates
Australian Nuclear Science & Technology Organization
Noranda Technology Centre

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Objective:

**To better understand the inter-relationships governing gas and heat transport in potentially acid-generating waste rock piles and develop guidelines for optimizing pile construction and cover systems to inhibit oxidation within the waste rock piles.**

Status:

**The project is being undertaken cooperatively by Nolan, Davis and Associates, and the Australian Nuclear Science and Technology Organization (ANSTO) who have developed the FIDHELM model. The model incorporates gas transport, heat transport, water transport and consumption of pyrite in the particles comprising a waste dump.**

**Data and experimental opportunities provided by the ongoing monitoring of a covered waste rock pile 7\12, at Heath Steele in New Brunswick (project 2.31.1) are being incorporated. The installation of six monitoring wells (3 pairs) in the uncovered pile 18B was completed last year. Also completed was a preliminary analysis of the Heath Steele waste rock piles using the FIDHELM model which identified the sensitivity of the pile to various parameters.**

**In situ measurements of gas permeability, thermal conductivity and gas diffusion have been made using the installed monitoring wells. The procedures for installation and monitoring have been documented in a comprehensive field manual which will be available in 1994.**

**Calculation of the critical parameters from the data collected is also covered therein. The temperature and oxygen probes attached to the monitoring wells have been monitored by telemetry on a monthly basis since installation, in conjunction with the data being collected from pile 7\12.**

**The model has been transferred to Nolan Davis and a customized graphical post processor is being developed in conjunction with ANSTO. Apart from the field manual, the final report is expected to address the simulation of gas transfer relationships under Canadian climatic conditions, the potential of isolating active material in the dump, different construction methods, and the application of cover systems. The latter will involve the comparison of reactivity in the uncovered pile 18B versus the covered pile 7\12.**

ACTIVE

PREDICTION - Basic Research
March 1994

**Project 1.31.2** **Residual Weathering Products in Waste Rock Dumps**
**Budget:** $40,000
**Sponsor:** ........................................................................................................................
........................................................................................................................
British Columbia
........................................................................................................................$20,000
Placer Dome........................................................................................$10,000
**Expenditures:** $19,910
**Manager:** W. Price, B.C. MEMPR
**Contractor:** University of British Columbia

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Objective:

The objective of this project is assess weathering products retained in a waste rock pile from a dump-leach mine site. Specifically this will entail:

- identification and characterization of the weathering products;
- development of probable mechanisms that relate bulk mineralogy to the secondary products formed; and
- estimation of the reactivity/stability of these secondary products under differing environmental conditions.

Status:

Investigations into the physical and chemical fate of residual weathering products within waste rock dumps are important factors in the development of a predictive chemical evaluation scheme. Investigations were initiated in 1993 at Gibraltar mines, British Columbia.

Four sites have been excavated at Gibraltar with the aid of a backhoe, and are approximately 4mx4mx4m. The sites are representative of rock dumps that have received acid leaching, and one that has weathered naturally. Samples have been collected based on morphological features, transported to the laboratory, air-dried and separated by size.

The fine fraction has been analyzed by X-Ray Fluorescence (XRF) for elemental content and X-Ray Diffraction (XRD) for dominant mineral species. XRD analyses were characteristic of the geological parent material, except that gypsum and jarosites were identified in several samples. The fine silt sized fraction exhibited a greater assemblage of mineral species than the sand sized fraction.

Laboratory analyses on elemental composition and relation to mineralogy and pit morphology will continue. Statistical analyses will be conducted to ascertain general relationships and trends. Micro-techniques will be conducted on representative samples to refine processes believed to be occurring at the mineral surfaces. The project is expected to be completed in early 1995.

ACTIVE

PREDICTION - Basic Research
March 1994

Project 1.32.2: Pyrite Oxidation - Lithological and Mineralogical Approach
Budget: $40,000
Sponsor: ..........................................................................................................................
..........................................................................................................................
British Columbia
..........................................................................................................................$20,000
Homestake .......................................................................................$ 5,300
Expenditures: $8,450
Manager: W. Price, B.C. MEMPR
Contractor: University of British Columbia

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Objective:

To investigate the effect of lithological and mineralogical factors on differences in the availability and reactivity of acid-generating or potentially acid-generating sulphide minerals.

Status:

Determining the relative oxidation rates of individual sulphide species is a basic and key prediction component as indicated in earlier work (1.32.1). The current program is studying the effects of rock fabric and composition on pyrite weathering rates to investigate the applicability of detailed mineralogical characterization to ARD prediction. The approach involves characterizing homogeneous units of environmental concern using a combination of quantitative mineralogical and modal composition to support present static and kinetic geochemical test methods.

A report summarizing a major literature review, as well as a refinement of the project outline has been completed. Materials have been collected and or sampled from Mount Milligan and Eskay Creek. The samples range from fresh to intensely surface weathered and include four major pyrite-bearing rock. Paste pH measurements have been completed and modified acid base accounting work will be completed in early 1994. Mineral carbonate carbon analysis by coulometrics has been initiated as well. Image analysis has been postponed to take advantage of the new image analysis system recently installed. Polished thin section petrography will provide an initial examination of sample mineralogy, texture and structure. Image analysis will examine surface details of pyrite crystals and fractures. The spacial relationship between pyrite, other sulphides and acid consuming minerals will be assessed. Microprobe analyses will be used to assess the composition of pyrite grains and identify possible patterns of compositional variation and X-Ray Diffraction will be used to identify clay minerals and other secondary weathering products.

The direction and progress of this masters thesis project is currently under review. Major changes are being considered for example for the electrochemical work initially proposed.

ACTIVE

PREDICTION - Modelling
March 1994

| | |
|---|---|
| Project 1.41.2: | ARD Waste Rock Monitoring Database |
| Budget: | $22,000 |
| Sponsor: | |
| CANMET | $22,000 |
| Expenditures: | $7,600 |
| Manager: | E. van Huyssteen, CANMET |
| Contractor: | University of British Columbia, Chair for Mining and the Environment |

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**Objective:**

The objective of the project is to develop a database to provide an overview of all significant ongoing and past field monitoring studies of acid or potentially acid generating waste rock dumps in Canada and internationally.

**Status:**

At the International Workshop on Waste Rock Modelling held in late 1992 (project 1.41.1), it was recommended that a listing of comprehensively monitored waste rock dumps be generated. The resulting database would be used to identify field information available for calibrating and verifying ARD modelling and prediction research.

Giving an overview of ongoing and previous field studies of ARD in waste rock, the database will contain information on what level of data is available from different mine sites and how to access it, rather than the actual data itself. The data to be obtained include: minesite location and biogeoclimatic conditions; waste rock characterization; physical dump characteristics; monitoring program details; and data access information.

Following a review of available data access systems, a PC Windows based application was chosen for the database. The task of creating customized data input forms and reports is nearly complete. The database is being constructed with five tables to contain information as follows: general mine information; general waste rock dump characterization; waste rock dump material characterization; monitoring program details; and data access. Details of the

**monitoring program are to include the parameters measured, the methods and instrumentation used, the temporal and spacial extent of measurements, and any data analysis or modelling done as well as a summary of any conclusions drawn.**

**As part of gathering of information, a questionnaire has been designed to solicit waste rock dump information and sent to over seventy contacts both in Canada and internationally.**

**Project 1.42.1:** Critical Review of Geochemical Modelling
**Budget:** $60,000
**Sponsor:** ..............................................................................................................
..............................................................................................................
....................................................................................................CANMET
....................................................................................................$30,000
Ontario....................................................................................$30,000
**Expenditures:** $0
**Manager:** H. Steger, CANMET
**Contractor:** Noranda Technology Centre
Alberta Research Council
University of Western Ontario

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**Objective:**

The two objectives of the proposed work are to identify the various geochemical processes occurring in waste rock piles at all stages of acid generation, and to list and thoroughly review existing geochemical models which are being used, or can be adapted, for predicting metal species and their concentrations in waste rock piles.

**Status:**

While considerable progress has been made in understanding oxygen and heat transport, predicting the geochemical processes and transport of metals in waste rock piles still remains a major challenge (project 1.41.1). The current project has been divided into two distinct tasks and addresses the available expertise related to modelling geochemical processes.

The contractor has recently been chosen through a competitive bid process. Based on the review of the proposals received, it has been recommended that a peer review of the first task be made prior to the initiation of the second task. The details of this review are being finalized.

The first task will involve the listing and review of controlling geochemical processes and input parameters for predicting species concentrations in waste rock piles. The focus will be

**primarily on reactions involving pyrite and pyrrhotite. The review is expected to include three fundamental inorganic leaching processes by which constituents are released from solids to solution: diffusion; stoichiometric (or bulk) dissolution; and intergranular dissolution which includes electrochemical dissolution.**

**The second task will examine what geochemical models are available to determine which have been used for acid water calculations, and to assess those that could be adapted for this purpose. Models to predict or examine geochemical processes have been loosely divided into five categories. These are phenomenological models, equilibrium models, mass transfer models, coupled mass transfer flow models, and others.**

**The project will be completed in late 1994.**

ACTIVE

PREDICTION - Basic Research
March 1994

**Project 1.51.1** **Quantitative Analyses of Chemical and Biological Kinetics**
**Budget:** $12,000
**Sponsor:** ............................................................................................
............................................................................................
Environment Canada
............................................................................................$11,750
**Expenditures:** $11,750
**Manager:** B. Godin, Environment Canada
**Contractor:** M. Otwinowski, Synergetic Technology

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Objective:

The objectives of the project are to provide quantitative analysis of the interrelated elementary chemical and biological processes which together are responsible for pyrite oxidation and acid rock drainage, and to determine whether the kinetic equations involved produce chaotic behaviour.

Status:

With the draft report in review, the project is near completion. The report reviews and critically analyses several experimental and theoretical results on chemical, physical and biological aspects of pyrite oxidation. In describing interrelated elementary chemical and biological processes associated with ARD, a clear distinction between oxygen requiring and non-oxygen requiring processes is made. The dependence of relative rates of reaction on pH are discussed and several experimental results and rate constants are reevaluated. Based on available information a kinetic model in the form of coupled nonlinear ordinary differential equations is constructed for the coupled chemical reactions responsible for ARD. The model is based on small-scale experimental data for pure pyrite.

Computer simulations for the concentrations of $H^+$, $Fe^{2+}$, $Fe^{3+}$, and $SO_4^{2-}$ have been performed for different values of the controlling chemical and physical parameters. The model does not include transport processes. Biological activity associated with pyrite oxidation is considered with respect to temperature, pH, available oxygen and other oxidants. Kinetic equations for biological activity are proposed for the first time.

The set of nonlinear kinetic equations considered in the study for the chemical reactions involved in pyrite oxidation does not appear to produce chaotic behaviour or other types of chemical oscillations. The report indicates however that the study does not exclude such physico-chemical oscillations when processes of water and oxygen transport are included.

Based on the review done, several areas which may merit further experimental and modelling studies are identified. The draft report recommends that the quantitative results presented therein be assessed with field data.

ACTIVE

PREDICTION - Basic Research
March 1994

**Project 1.51.2:** Nonlinear Modelling of Chemical Kinetics for Acid Mine Drainage
**Budget:** $30,000
**Sponsor:** ........................................................................................................ Environment Canada ........................................................................................................ $34,550
**Expenditures:** $34,550
**Manager:** B. Godin, Environment Canada
**Contractor:** J. Tuszynski, University of Alberta

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Objective:

To determine the initial conditions that will lead to chaotic behaviour and other nonlinear behaviours and determine the area of predictability versus non-predictability in ARD chemical evaluations.

Status:

The project is near completion, with the draft final report currently being reviewed. The reduction of impact from ARD requires accurate prediction. However, as is discussed in the report, the complexity of the chemical reactions involved precludes an easy and simple approach to the problem. The chemical processes are not only strongly dependent on external conditions (weather etc.) and the geology of the terrain but, they also involve feedback loops making the problem inherently nonlinear. Accurate prediction must also account for competition between neutralization and acid generation.

The project is chiefly concerned with the modelling of nonlinear kinetics of the chemical reactions present in both acid production and neutralization that are associated with the ARD process. An extensive literature survey encompassing both geochemical analyses regarding AMD and the relevant aspects of nonlinear chemical kinetics has been carried out. The report looks at the chemical reactions involved in chemical oxidation of pyrite, ie. type, activation energy, rate, and thermodynamics. A theoretical mathematical model, rather than empirical, has been used to explore a wide range of extreme situations to uncover non trivial behaviour. No chaotic behaviour is found in the case of pyrite oxidation. The sulphide chemical oxidation

**does intrinsically produce variability in results. Therefore based on chemistry alone, it is possible to predict ARD outcomes. Irregular variations in chemical species concentrations are observed and this irregular behaviour seems to be mainly affected by the porosity of the medium and the presence of non-zero flow rates of oxygen and water.**

**The draft report indicates that no chemical chaos exists in the pyrite oxidation, but that the effect of physical processes may have a greater effect on the predictability of acid rock drainage problems.**

Project 2.11.3ab: **Evaluation of Underwater Disposal Site - Anderson Lake**
Budget: $400,000 a: $125,000, b: $275,000
Sponsors:..........................................................................
..........................................................................
.......................................................................... HBM&S
..........................................................................$214,000
CANMET..........................................................................$180,000
Environment Canada ..........................................................................$ 6,000
Expenditures: $235,000
Manager: J. Robertson, Placer Dome
Contractors: Rescan Environmental, ASL Laboratories
University of British Columbia, Environment Canada (NWRI)

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## Objective:

The objective of the Anderson Lake program is to address the recommendations made by the Peer Review and to provide the additional information needed to support the application of the subaqueous disposal method. Two lakes were selected to continue the program; Buttle as a deep lake and Anderson as an active, relatively shallow site. The specific objective of this program is to obtain a clear understanding of the metal fluxes at the sediment/water interface.

## Status:

Specific comments from the Peer Review focused on the requirements for additional work on Quality Assurance/Quality Control (QA/QC) on all phases of the program from sampling to analysis to yield statistically valid results. Research currently in progress is employing a combination of high resolution water-column sampling and solid-sediment and interstitial water sampling to assess the reactivity in the basin. The work is being conducted on a seasonal basis to allow determination of the influence of a number of variables on the distribution of dissolved and particulate metals in the water columns, and the extent of chemical exchange with the underlying sediments. For example, sampling in ice-covered Anderson Lake in late winter 1993 (2.11.3a), revealed a profound multi-layer stratification in which steep temperature increases with depth were accompanied by severe depletions in the dissolved metals. Detailed porewater metals measurements showed that the dissolved metals levels in the submerged tailings were extremely low, implying that the tailings were not supporting an

**efflux of metals from the bottom.**

**A second sampling campaign (2.11.3b) was completed in mid-August 1993. The results obtained during the ice-covered period will be compared with data obtained from mid-August, where stratification is expected to be less profound.**

**The timing of the Anderson campaigns was critical in that the metallurgical operation using the site, the only active subaqueous disposal site available for study, is scheduled for shutdown in early 1994. A further post-production campaign will be completed, probably in late summer 1994 (2.11.3c).**

**Project 2.11.4a:** Evaluation of Underwater Disposal Site - Buttle Lake
**Budget:** $250,000
**Sponsors:**

| | |
|---|---|
| Placer Dome | $ 94,000 |
| CANMET | $150,000 |
| Environment Canada | $ 6,000 |

**Expenditures:** $85,000
**Manager:** J. Robertson, Placer Dome
**Contractor:** Rescan Environmental, ASL Laboratories
University of British Columbia, Environment Canada (NWRI)

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**Objective:**

The objective of the Buttle Lake program is to address the recommendations made by the Peer Review and to provide the additional information needed to support the application of the subaqueous disposal method. As part of the program it was agreed that additional studies would focus on two different lakes: Anderson Lake (a shallow lake) and Buttle Lake (a deep lake). The specific objective of this measurement program is to obtain a clear understanding of the metal fluxes at the sediment/water interface.

**Status:**

Buttle Lake, located in Strathcona Park on Vancouver Island, presents an opportunity to study the reactivity of mill tailings from a deep discharge which is now covered by a veneer of almost one decade's worth of natural sediment. Of particular interest is the reactivity of the tailings that have been admixed with natural, surficial sediments as they have been exposed to oxygenated bottom-water since the time of original deposition.

In keeping with the recommendations of the Peer Review (2.11.1d), a work plan that addresses the key issues of QA/QC and salient aspects of sediment chemical-seasonality was developed. The work addresses tailings reactivity by high-resolution observation of trace-metals and other sensitive "tell-tale" indicators within the interstitial waters of the sediments and across the sediment-water interface. This was completed using a combination of sampling methodologies

**including: discrete water-column sampling and profiling, extrusion and centrifugation of cores, as well as the use peepers to integrate sediment and water-column chemistry.**

**A sampling campaign was completed on Buttle Lake in October 1993 (2.11.4a). It is possible that a second sampling campaign will be undertaken in late 1994 (2.11.4b).**

**Preliminary results from the 1993 programs on Buttle Lake and Anderson Lake (2.11.3ab), particularly the high-resolution water column sampling, confirm the tentative findings from earlier studies for tailings reactivity.**

ACTIVE

P&C - Wet Barriers
March 1994

**Project 2.13.1:** Flooding of Existing Tailings Sites - Quirke Lake
**Budget:** $835,000
**Sponsors:**
Rio Algom ....................$502,000
CANMET ....................$333,000
**Expenditures:** $835,000
**Manager:** A. Vivyurka, Rio Algom Limited
**Contractors:** Rio Algom Limited/CANMET

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**Objective:**

The objective of this project is to investigate the feasibility of establishing a wet barrier, such as a water and/or wetland cover on pyritic uranium tailings to:

- act as an oxygen barrier, and hence control acid generation;
- stabilize the tailings surface; and
- minimize surface and groundwater contamination.

**Status:**

During the spring of 1989, Rio Algom and CANMET began a joint project to assess the feasibility of flooding the existing Quirke tailings site as a close-out option. To date the following has been completed:

- literature review on wetlands and their role in treating acid mine drainage;
- field evaluations of wetland sites (hydrogeochemical and biological characterization);
- wetland vegetation transplantation, survival and propagation studies on tailings;
- column leaching lysimeter tests (oxidation, leaching and neutralization characteristics); and
- preparation of a large-scale field demonstration program (65 ha). This included levelling of the tailings surface, limestone addition, liquefaction study, piezometer installation, flow control structure, continued sampling and monitoring during and after flooding.

**Flooding of the 65 hectares test site commenced in November 1992 and was completed in Spring 1993. Monitoring of the test site and the laboratory columns is ongoing.**

**Work that is scheduled for 1994 includes:**

- **monitoring of the cover and the laboratory columns (until spring); and**
- **preparation of a final report summarizing the laboratory studies and a final monitoring report on the field test site.**

**Discussions are also underway with Rio Algom for the release of pertinent reports (e.g. feasibility of water covers, site hydrology, dam design) on the project.**

ACTIVE

P&C - Wet Barriers
March 1994

| | |
|---|---|
| Project 2.13.2a: | Flooding of Existing Tailings Sites - Solbec Cupra |
| Budget: | $260,000 (1993 - $ 137,700) |
| Sponsors: | Cambior $32,300 |
| | Québec $32,300 |
| | CANMET $73,100 |
| Expenditures: | $262,000 |
| Manager: | L. Bienvenu, Ministère de l'Énergie et des Ressources (MER) |
| Contractors: | Roche Ltée., Université Laval, McGill University |

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**Objectives:**

The objectives of this project are to determine if a water cover prevents the continued oxidation of acidic tailings (containing ≈30 to 50% sulphide), and to establish the minimum water depth needed, while considering wind, waves, permeability of the sub-soils and the hydrology of the drainage basin.

**Status:**

The first phase of the project (1989 - 1990) involved the installation of instrumented experimental basins with a one-metre water cover and watertight sides. Results confirmed that a water cover prevents the oxidation of fresh tailings. However, porewater samples taken in the oxidized tailings are acidic, even after flooding. In 1991 a hydrogeological study of the tailings basin confirmed that flooding of the tailings is possible with natural precipitation and surface runoff over an eighteen-month period. Construction of impervious dams and/or levelling of the tailings surface at the south end will be required to maintain a one-metre water cover. Another basin where lime has been added to the oxidized tailings was completed in 1992.

Monitoring of all the lysimeters was continued until December 1993 and a synopsis report evaluating the collected data will be available in 1994. Two other research projects were started in 1993. The minimum depth of water required to prevent resuspension of solid particles through wind action was found to be 1.34m. However, with a layer of sand on top of the tailings the required level may be reduced to 0.7m. In another related study on the microbiological considerations it was found that there was no bacterial activity in the 1989 flooded lysimeters. However, a large bacterial population was found outside the experimental basins in the oxidized tailings. Both of these reports should be available in 1994.

Cambior is planning on flooding the site starting in 1994 pending government approval and the procurement of several lots in the vicinity of the tailings basin.. One project that would be considered if flooding is commenced in 1994 is a field monitoring program during and after flooding.

**Project 2.15.1:** A Study on Water Covers for the Decommissioning of Mine Waste Disposal Sites
**Budget:** $487,000
**Sponsors:**

| | |
|---|---|
| Noranda Technology Centre | $253,000 |
| INCO | $ 85,000 |
| Lac Minerals | $ 15,000 |
| Ontario | $ 30,000 |

**Expenditures:** $298,000
**Manager:** R. Michelutti, Falconbridge
**Contractors:** Noranda Technology Centre (NTC), CANMET (Elliot Lake)

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Objective:

The project is using laboratory, numerical, and field methods on oxidized tailings to obtain the parameters necessary for evaluating the effect of different depths of water cover on the long-term quality of the overlying and interstitial water. A laboratory lysimeter Testing Procedures Manual for the flooding of oxidized tailings option will be produced.

Status:

Covering old sulphidic tailings sites with water has been proposed as a method for reducing sulphide oxidation and the generation of AMD. The method usually involves the construction of containment structures around the tailings deposit to hold water. Since the oxygen diffusion coefficient and solubility in water are very low, oxygen influx to the tailings is effectively reduced. However, metals present in pore water solutions and in soluble mineral phases before the implementation of the water cover will continue to be released from the tailings. The concentrations and loadings of the released metals can be important enough to require lime treatment of all runoff and seepage water leaving the tailings for a long time after cover placement. Metal types, concentration and loadings, as well as variations with time, have to be known to confidently evaluate the costs and benefits of using a water cover for decommissioning.

The project is being conducted jointly by NTC and CANMET. NTC is studying the diffusion coefficients and fluxes, and has started field tests at Mattabi. Some preliminary results from the laboratory and field studies with the Mattabi tailings suggest that leaching of zinc from the tailings may occur for a long period of time after flooding. It is therefore anticipated that treatment of surface and seepage water may be required. It was also recommended that surface amendments be used with oxidized materials to control the secondary minerals dissolution into surface waters. Ongoing studies will investigate the processes and rates in more detail.

CANMET is studying the oxygen diffusion characteristics, the wave action and sediment erosion characteristics and contaminant transport flux measurements. Work began in late 1993 because of delays in obtaining funding.

**Project 2.20.1:** Evaluation of Alternate Dry Covers for the Prevention of Acid Mine Drainage from Tailings

**Budget:** $50,000

**Sponsors:**

| | |
|---|---|
| Lac Minerals | $ 5,000 |
| Ontario | $25,000 |
| CANMET | $25,000 |

**Expenditures:** $40,000

**Manager:** L. Surges, BM&S

**Contractor:** SENES Consultants Limited

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**Objective:**

The objective of this study is to review the dry covers theory and current research, evaluate potential materials including several which have not yet been evaluated for use in covers, and after evaluation, provide recommendations regarding further dry covers research.

**Status:**

The draft report was received in mid-December and is currently under review. This report will assist the Prevention and Control Committee to select the best, most economical alternatives for which laboratory and field test programs can be developed.

One of the primary methods of preventing acid mine drainage from tailings is the placement of a cover which reduces the amount of oxygen and/or water that contacts the acid-generating sulphides. The theoretical concept of dry covers was reviewed and the barriers classified as oxygen barriers (moisture retaining), oxygen consuming, or reaction inhibiting. Potential barrier materials were identified through a technical literature search. The literature review focused on forest product industry wastes, and a search for potential materials that may be obtained from municipal and industrial wastes. A short list of potential materials was developed applying a two-stage screening process which takes technical aspects, cost, and practical application into consideration. Potential barrier materials considered to provide broadly based (country wide) benefit and a good likelihood for success are listed.

**Recommendations are made regarding the future direction of dry barriers research and specific research work currently underway.**

**Potential materials given a high priority for future research include natural soils, modified soils, desulphurized tailings, tailings slimes, wood waste, and paper mill sludge. Materials given a lower priority for future research include peat, waxes, ashes, and the PHITO layer. Available barrier materials not requiring additional research are limestone (mixed into the tailings mass), and synthetic liners.**

ACTIVE

P&C - Dry Barriers
March 1994

**Project 2.22.2:** Evaluation of Dry Covers Built from Mine Tailings
**Budget:** $234,880
**Sponsors:** ..........
..........Québec
..........$133,000
Ressources Ste-Geneviève ..........$ 20,000
Lac Minerals..........$ 10,000
CANMET..........$107,000
**Expenditures:** $160,000
**Manager:** L. Bienvenu, Ministère de l'Énergie et des Ressources (MER)
**Contractor:** École Polytechnique

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Objective:

The objective of this study is to evaluate, under controlled laboratory conditions, the effectiveness of using fine tailings as an alternative for the capillary material in layered cover systems to control acid mine drainage (AMD).

Status:

In most of the projects currently underway in Canada and abroad, dry barriers are usually constructed from naturally occurring geological materials (till, silt or clay) maintained at a high degree of saturation to minimize the diffusion of oxygen through the cover. Because low permeability soils may not be readily available, alternate materials (e.g. mine tailings) having somewhat similar physical properties may be substituted.

More than 30 tailings sites were sampled and analyzed as possible cover materials and a state-of-the-art literature review was completed. Preliminary tests, including mineralogical analyses, grain size determination and Atterberg limits, allowed the selection of four sites where the tailings were sampled again for more detailed studies. The results confirm that sulphide-free fine tailings offer some promising characteristics as cover materials. For example, it has been shown that, when the void ratio is reduced, the permeability of tailings can be as low as $1 \times 10^{-6}$ cm/s, which compares very well with that of silts and tills. Also from the sieve analyses and available data in the literature, it is expected that fine tailings can maintain a high degree of saturation when they are used in a layered system because of their relatively high water retention capacity. Suction curve studies on tailings have recently confirmed this. Recent work described in the literature shows that silty soils, with physical properties similar to some of the tested tailings, can be used with success to limit AMD.

Laboratory column tests and some preliminary modelling of a proposed cover design are in progress. These column tests are used to determine hydraulic and diffusion characteristics of the materials. The results of the column tests will provide the basic data that, starting from diffusion equations, allows a preliminary evaluation of the cover performance. Long-term tests on control columns are also being done to evaluate, using various predictive models, the actual effect of covers on acid generation. Some preliminary cover configurations using simple theoretical models are also being looked at. Large scale tests for these cover systems are being considered.

ACTIVE

P&C - Others
March 1994

Project 2.23.2c: A Tracer Study of Fluid and Contaminant Movement in the Upper Surface of the Thickened Tailings Disposal (TTD) System at Kidd Creek Mines
Budget: $78,200 (1993 - $22,000)
Sponsors:....................................................................................................
....................................................................................................
....................................................................................................Falconbridge
....................................................................................................$39,100
Ontario....................................................................................................$20,000
CANMET....................................................................................................$20,000
Expenditures: $25,000
Manager: D. Bordin, Falconbridge Limited (Kidd Creek Division)
Contractors: E.I. Robinski Associates Ltd.
University of Saskatchewan

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Objectives:

The objectives of this study are to verify modelling results of the behaviour of thickened tailings disposal against field observations. Specific objectives include determining the net infiltration due to climatic flux, the pathway and rate of infiltrating water and the role played by the zone of capillary saturation in the attenuation of infiltration and contaminant migration.

Status:

During the autumn of 1992, one hundred and thirty-five mini-piezometers were installed at three test sites on the tailings deposit. The three sites were located downslope and in increasing distance away from the top of the cone. Two salts were chosen as a chemical tracer, potassium bromide and potassium iodide, which have high solubilities and are not originally present in the tailings. The presence of the anions in samples would be indicative of contaminant migration through the system. The system was subsequently "seeded" during the fall of 1992 and the initial sampling campaign was completed in June 1993. An earlier sampling was not possible because of the frozen tailings surface. A second sampling campaign was completed in September. Samples were then analyzed by ion chromatography.

The hydrogeology of the cone was studied (Project 2.23.2ab) and it was predicted that average pore water velocities were quite low, ranging from 0.1 cm/yr to 69 cm/yr which would allow for low contaminant migration rates. Results to date indicate pore water velocities to be slightly higher than predicted but compare favourably to those of clay materials. Further testwork is to be completed as to the interpretation of the data and possible influences by such events as rainfall, etc. The data also confirmed a strong downward gradient.

Field monitoring is to continue for another year. The final year (1995) of this project would use the results to calibrate models on the performance of the TTD method with respect to seepage and contaminant transport.

ACTIVE

P&C - Others
March 1994

Project 2.23.2d: Geochemical Evaluation of the Thickened Tailings Disposal (TTD) System at Kidd Creek Mines

Budget: $250,000

Sponsors:

| | |
|---|---|
| Falconbridge | $125,000 |
| Ontario | $ 60,000 |
| CANMET | $ 60,000 |

Expenditures: $170,000

Manager: D. Bordin, Falconbridge Limited (Kidd Creek Division)

Contractors: University of Waterloo\CANMET

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Objectives:

The objectives are to determine the geochemistry of the tailings cone through the pore water chemistry and the control mechanisms as well as a whole rock study of the cone solids.

Status:

In contrast to most conventional tailings ponds, tailings disposal by the thickened, sloped, discharge system results in a gently sloping deposit of tailings without a slimes pond and without high perimeter dams. The literature indicates that thickened tailings disposal provides a homogeneous tailings mixture which exhibits moisture retention characteristics and low hydraulic conductivities that aid in the abatement of acid generation.

In Phase A, samples were collected and analyzed from 27 piezometer nests. Pore water cation and anion analyses were completed. Initial chemical analyses was conducted on samples to determine concentrations of Ag, Al, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, Rb, Sr, Zn, As, Se, and Si ($SiO_2$) performed by AAS, and $PO_4$, $SO_4$, $NO_3$, F and Cl, by ion chromatography. Eh, pH and alkalinity measurements were conducted in the field. Tailings mineralogical data were also collected.

In Phase B, pore water from two piezometer nests were used to assess the affects of jarosite co-disposal with both tailings and sulphide oxidation on pore water quality. Jarosite has been co-

**deposited with the tailings since 1985. Piezometer nests were chosen where limited tailings deposition has occurred for the past 5 to 7 years to best represent oxidized areas. For fresh tailings, locations near the discharge, where tailings deposition has occurred with and without jarosite, were chosen as representative of initial conditions. The data collected were compared to the present mill discharge water composition which would be used as the baseline conditions for pore water composition.**

**Pore water concentrations of Fe, $SO_4$, Na, K, and Pb were plotted versus depth at piezometer nests along a north-south cross section. Hydraulic gradients, conductivities and porosities were measured and distances for advective solute transport were calculated. Geochemical equilibrium modelling was completed using MINTEQA2. A final report is to be issued in 1994.**

ACTIVE

P&C - Others
March 1994

**Project 2.23.3:** Porous Envelope Surround Disposal Method - Falconbridge
**Budget:** $123,000
**Sponsor:** ........................................................................................................................................
..................................................................................................................................................................
............................................................................................................................Falconbridge
..................................................................................................................................................$79,000
Ontario........................................................................................................$61,000
**Expenditures:** $140,000
**Manager:** M. Wiseman, Falconbridge
**Contractors:** Noranda Technology Centre
Geomar Geophysics Ltd.

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**Objective:**

The objective of this project is to evaluate the feasibility and effectiveness of the porous envelope surround disposal concept, used for their pit tailings disposal at Rabbit Lake in Saskatchewan, to be extended to controlling acid mine drainage.

**Status:**

A porous envelope may occur in groundwater systems when mine tailings of low permeability are placed within high permeability soils. If the permeability contrast between the tailings and the natural soil is large, groundwater will flow around the tailings mass rather than through it, and metal leaching will be minimal.

Preliminary hydrogeological observations at Falconbridge's Fault Lake tailings site suggest that permeability contrasts between the natural till deposits and the tailings may be sufficient for porous envelope containment to occur. The tailings have been deposited in a kettle lake formed within glacial outwash sand and gravel.

In an effort to minimize costs, Falconbridge has had electromagnetic surveys completed at the site. These non-intrusive techniques were cost effective in identifying groundwater contamination plumes thus facilitating the installation of the required scientific equipment in 1992 in the areas identified by the survey.

**The measurement of hydraulic properties, hydrogeological analyses with numerical modelling and chemical monitoring of appropriate parameters existing on site are ongoing. It has been found that the tailings are mostly above the water table, except for the tailings located in the former kettle lake where a water table was found. Surveys using a combination of electromagnetic geophysical methods and monitoring wells did not detect any presence of metals in the groundwater surrounding the tailings. A 2-D finite-element numerical model was used to predict conditions which may occur if the water table would rise within the tailings in locations other than the former kettle lake. The model suggested that the contribution of tailings leachate to the regional groundwater system would be small.**

**Project 2.25.1:** Reclamation of Sulphide Tailings Using Municipal Solid Waste Compost
**Budget:** $130,000
**Sponsors:** ..........
..........Falconbridge
..........$53,500
Ontario..........$32,500
**Expenditures:** $76,000
**Manager:** M. Wiseman, Falconbridge
**Contractors:** Laurentian University
Falconbridge

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**Objective:**

The objective of this study is to conduct laboratory and field scale demonstrations on the use of municipal solid waste compost as cover in an abandonment strategy for mine tailings.

**Status:**

The first stage of the project was to conduct a literature review of what is known about the physical and chemical characteristics of municipal solid waste (MSW) compost and other organic materials. A copy of the literature review and recommendations report is available from CANMET (2.25.1a). The conclusions of the survey led to laboratory research, started in 1992, to evaluate the physical and chemical characteristics of compost, compost leachate characteristics, and the impact of compost compaction and compost maturity on these characteristics. This was followed by the development of columns to further evaluate compost/tailings hydrology, concentration of different gases, pH and Eh, changes in tailings leachate chemistry, as well as mineralogy. Laboratory research is ongoing and to date has proven that compost covers can establish the conditions necessary to stop and reverse the acid drainage process but some reductive dissolution of metals has also been noticed and is being further evaluated.

An economic evaluation, recognizing the practical and regulatory conditions in Ontario, suggests that utilizing thick covers of low grade compost has both practical and economic justification for both the mining industry and municipalities. In conclusion, laboratory research has shown that the utilization of low grade compost covers to establish anaerobic

**reducing conditions on tailings has the potential to be a low cost strategy for tailings abandonment.**

**At the completion of the laboratory work, a go/no-go decision will be made. Stage 3 is the construction of pilot scale and/or field lysimeters to simulate field conditions.**

**Recognizing the potential reductive dissolution concern with a compost cover, it was recommended that the detailed field study be moved from the Nickel Rim site to Falconbridge's "New Tailings" site where background surface and groundwater data is available and leachates can be contained and treated.**

ACTIVE

P&C - Dry Barriers
March 1994

**Project 2.25.2:** Design of an Organic Barrier Using Wood Waste - East Sullivan
**Budget:** $431,000 (1993 - $ 57,000)
**Sponsor:** ........................................................................
........................................................................Québec
........................................................................$351,000
**Expenditures:** $177,000
**Manager:** L. Bienvenu, Ministère de l'Énergie et des Ressources (MER)
**Contractors:** Roche Environmental Ltd.
Centre de recherches minérales

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## Objective:

The objective of this study is to evaluate the effect of forestry by-products such as wood waste on the process of tailings acidification and the effect of organic amendments on the quality of the surface and groundwater at the East Sullivan tailings site in northwestern Québec.

## Status:

MEND is evaluating a number of organic covers which are classified as oxygen consuming layers. It is perceived that the organic materials will create a strongly reducing layer due to the continued biological degradation of the organics and other processes. These covers may require the intermittent addition of new organic material to maintain the oxygen scavenging capability. Covers composed of forest waste or other organic wastes will be useful for the mining industry only if they provide a permanent, socially-acceptable and cost-effective solution to tailings management.

A preliminary field test, on a 10 m X 10 m test plot in old wood waste at East Sullivan, was completed in 1991. The results demonstrated that a one-metre wood waste cover effectively blocks access of oxygen which could oxidize underlying sulphates, as shown by the fact that methane is generated. However there were concerns regarding leachate quality.

In 1992 six 20 m X 20 m experimental test plots, with monitoring instrumentation, were constructed on the East Sullivan site. First year monitoring results focused on the gas concentrations in the wood wastes have shown that the oxygen concentration dropped from 16.1% to less than 1.5% at a depth of 70 cm and $CO_2$ levels increased from 8.2% to 50.8%.

Three separate elements were defined for this project. Construction of the test plots is completed and monitoring will continue for another two years at the East Sullivan tailings site. The third element is a more generic evaluation of how organic layers function. Several concerns need to be addressed for this abundant, renewable resource for cover application including physical and chemical variability (surface area, moisture content temperature), long-term stability (e.g. replenishment), design criteria (e.g. optimal cover depth, particle size, method of application) and undesirable leachates (e.g. dissolved organic material). Funds may be solicited for generic type research in organic covers in 1994 following the review of the recommendations in the Dry Covers Evaluation report (2.20.1).

**Project 2.31.1b:** Dry Covers on Waste Rock - Heath Steele
**Budget:** $367,700 (1993 - $48,000)
**Sponsors:**

| | |
|---|---|
| Noranda - BM&S (Heath Steele) | $121,300 |
| CANMET | $154,500 |
| New Brunswick | $ 91,900 |

**Expenditures:** $298,000
**Manager:** L. St- Arnaud, Noranda Technology Centre
**Contractors:** Nolan Davis and Associates, Heath Steele Mines

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**Objective:**

The objective of the project is to evaluate the effectiveness of a soil cover as a method of long term management of acid-generating waste rock. Project 2.31.1b consists of applying the cover, designed in Project 2.31.1a to Pile 7/12 and monitor the cover performance for three years.

**Status:**

Work started on the cover in August 1991. The cover consisted of a 30 cm thick sand base, a 60 cm thick compacted glacial till, a 30 cm thick granular layer, and a final 10 cm thick gravel layer for erosion protection. The three-layer cover system and monitoring instrumentation installation was completed in September 1991. The performance of the composite cover has been monitored on a continuous basis since. A second pile (18B) is also being monitored as a control.

Results indicate a reduction in gaseous oxygen concentrations in the pile from 20% before cover to about 3% after cover placement. The decrease in oxygen penetration implies reduced oxygen flux and acid production. Volumetric water contents averaged 32% in the till at installation and had not changed 7 months later. Temperatures in the pile have decreased following cover installation but appear to be more influenced by climatic variability than by a decrease in heat production and hence sulphide mineral oxidation. Observed discharge from two lysimeters, installed below the cover, indicates infiltration of 2 to 2.5% of precipitation during a 55-day period when rainfall was heavy. The quality of seepage from the pile has not changed since cover installation. A report on the "Engineering Design and Construction" of the cover and two years of monitoring data will be available in 1994. Further monitoring will be required and will continue in 1994 to confirm the reduction in acid production because of the presently stored acidity and low percolation of water through the cover.

The data collected on Pile 7/12 is also being used to compare the reactivity with an uncovered pile (18B) using the ANSTO developed FIDHELM model (1.22.1).

The final output of project 2.31.1b will be a performance evaluation report describing the effectiveness of engineered natural covers on waste rock. The collected data will also be used in a design criteria document that can be used by others for construction purposes.

**Project 2.32.3a:** Injection of Mine Tailings into a Waste Rock Pile as a Method to Control AMD - Literature Review

**Budget:** $10,000

**Sponsors:**..........................................................................................................................

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..........................................................................................................................................Québec

..........................................................................................................................................$10,000

**Expenditures:** $9,990

**Manager:** J. McMullen, Lac Minerals

**Contractor:** Laval University

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Objective:

The main objective of this project is to evaluate the feasibility of injecting mine tailings into a waste rock pile as a method to control acid mine drainage. The first phase will identify the problem, complete a literature review of pertinent information and develop a work plan for laboratory experiments on the most promising techniques identified in the review.

Status:

Acidic drainage generation in waste rock poses a much different problem from that of tailings because of the huge difference in the size of the waste materials. Waste rock piles contain large voids which allow water and air (due to temperature gradients and porosity) to freely penetrate the pile and these conditions promote accelerated bacterial and chemical reactions which are so strong that elevated temperatures (45-60°C) and convection cells (chimney effects) have been observed.

The prime function of injecting tailings into a waste rock pile is to reduce porosity and permeability and increase the degree of saturation of the pile. The result will be a major reduction of air entering the waste rock pile thus eliminating convection, if present and consequently reducing the reactions causing acidic drainage. It also has the advantage of using a waste product.

The literature review revealed that the injection concept is a unique method that has not been tried before. The review centred on possible analogous research that could be applied (e.g.

**hydraulic backfill, flow transport modelling, cementing additives, physical parameters, etc..) to develop the injection process. Based on these findings a laboratory program was developed and may be proposed to the Prevention and Control committee in the future.**

| | |
|---|---|
| **Project 2.34.1** | **Use of Cementitious Covers to Control Acid Generation at Westmin's HW Mine - Shotcrete Field Trial** |
| **Budget:** | **$130,000** |
| **Sponsors:** | |
| | **Westmin ........ $100,000** |
| | **CANMET ........ $ 30,000** |
| **Expenditures:** | **$130,000** |
| **Manager:** | **R. van Dyk, Westmin** |
| **Contractors:** | **Northwest Geochem and Powertech Labs** |

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**Objective:**

**The objective of this program is to evaluate the long-term effectiveness of a large-scale shotcreted cementitious cover as a means of preventing water and oxygen infiltration into waste rock piles. In addition, the test provides an opportunity to develop better automated techniques for large-scale application of the shotcrete cover material.**

**Status:**

**Previous studies completed at the Westmin site have shown that, on the basis of laboratory tests and limited field studies, the approach of using cementitious materials as a cover and grouting medium appears to be viable and cost effective, and that further investigation of field application techniques should be pursued. This project is a follow-on from the recommendations made in the previous study.**

**Approximately 3500 square metres of waste rock was covered using the shotcrete process in August 1992. A robotic arm mounted onto a vehicle was used to apply the shotcrete onto the rock slope. The cementitious material used in the project incorporated high volumes of fly ash (a waste product) to reduce the material cost. The shotcrete mix also included the use of polypropylene fibres to control cracks. The test area was instrumented with survey markers to monitor settlement in the rock slope.**

**The performance of the test area has been monitored to evaluate the durability of the cover**

**when subjected to field conditions. Compressive strength increased over the one-year monitoring period and all samples achieved or exceeded the design criteria. Some hairline cracks, formed during the curing period. Some cracks have penetrated through the cover and work is progressing to see how much moisture has reached the waste rock. Monitoring of the cover performance has continued until the end of 1993 and a final report will be submitted in 1994.**

**A major consideration in the design of the testing program was cost. The transportation of aggregate to the mine site was the largest cost for this project. If a local aggregate source, such as coarse tailings, was available the unit cost per square metre of cover could be less than twelve dollars (from an estimate of $18.46), a saving of approximately 30 percent.**

ACTIVE

P&C - Waste Rock
March 1994

Project 2.35.2: Lysimeter Evaluations of Cover Alternatives - Noranda
Budget: $195,000
Sponsors:........................................................................ Noranda
........................................................................$115,000
Québec ........................................................................$ 83,600
Expenditures: $198,600
Manager: L. St-Arnaud, Noranda Technology Centre
Contractors: Noranda Technology Centre\McGill University

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Objective:

The objective is to evaluate the relative effectiveness of different measures in preventing and controlling sulphide oxidation and hence acid generation in waste rock under field conditions.

Status:

The experiments were started in June 1991 and weekly monitoring of the drainage water from the lysimeters have been in progress since then. The control techniques being investigated are water cover, soil cover, wood bark cover, and addition of limestone and phosphate rock (apatite). Potentially acid-generating waste rock samples used in the investigation were obtained from the Stratmat mine in New Brunswick and from Les Mines Selbaie in Québec. The investigation involved outdoor lysimeter tests and indoor laboratory column experiments. The first milestone report will be available in early 1994.

Monitoring of the effluent water quality up to about 60 weeks indicated the control waste rock started producing acid very early in the tests (≈ 5th week). The rate of acid production was quantified and found to be higher in the laboratory than outside. Higher laboratory temperatures were most probably the reason for the higher rate.

The most effective control technique over a 60-week period was water cover, followed by 3% and 1% limestone, soil cover, and finally 3% and 1% phosphate. All the techniques, with the exception of the water cover (same results), were found to be slightly more effective in the laboratory than outside. In these tests it was found that the wood bark accelerated acid production in the laboratory and outside. The organic nutrients from the wood are believed to have promoted the iron oxidizing bacteria (*Thiobacillus ferrooxidans*) and this may explain this acceleration. Different results are being observed for wood bark covers in Project 2.25.2. The difference is probably explained by oxidizing conditions in the lysimeters versus reducing conditions in the field. Monitoring will be completed in 1994 and the final report describing the relative effectiveness and longevity of the techniques in controlling acid production will be submitted for review.

Aqueous geochemical modelling of the effluents was completed by McGill over a 16-month period. The modelling indicated that the removal of some metals such as iron, lead, zinc and manganese from the effluent solution was partly due to the formation of mineral solids.

**Project 2.42.1:** Development of Synthetic Polymers - Laurentian
**Budget:** $83,000 a: $45,000 b: $38,000
**Sponsors:** ........................................ INCO ........................................ $22,500
Ontario ........................................ $22,500
**Expenditures:** $35,000
**Manager:** W. Kipkie, INCO
**Contractor:** Laurentian University

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**Objective:**

The project objective is to synthesize a polymeric material(s) with specific engineering characteristics. The ideal material(s) would have the following properties, in tailings ponds, it would: a) be water soluble; b) provide long-term bactericidal action; c) strongly adsorb onto particulate matter; d) flocculate fines when wet; e) act as a binding agent for fines when dry; and f) complex any previously leached metals. In waste rock it would also: g) be readily foamed to allow penetration into the pile; and h) have virtually no oxygen permeability.

**Status:**

A number of approaches have been tried in synthesizing various components of the required polymer(s). As anticipated, most were not effective and efforts have been focused on those showing significant results.

Work on heavy metal chelating polymers has focused on the development of a synthetic route that would produce 100% polyvinyl amine (XPVAm) in good yield. This polymer is reacted with chloroacetic acid to obtain a structural feature that approximates an EDTA structure. Synthesis of bactericidal polymer has also been started and partially worked out.

This is a three-year research project, of which the first two years are MEND approved. A go/no go decision is incorporated into the program at the end of each of the first 2 years. Because of the slow start-up problems, the first go/no go decision has been deferred to the end

**of March. No further funds will be allocated until after that time.**

**Project 2.45.1a:** Separation of Sulphides from Mill Tailings
**Budget:** $75,000
**Sponsors:**

| | |
|---|---|
| CANMET | $20,000 |
| Ontario | $20,000 |
| Lac Minerals | $15,000 |
| Placer Dome | $10,000 |
| Les Mines Selbaie | $10,000 |

**Expenditures:** $35,000
**Manager:** G. Hope, Lac Minerals
**Contractor:** CESL Engineering

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## Objectives:

The objectives of this project are to evaluate various mineral processing techniques that could be applied to the separation of sulphides in tailings, evaluate the relationship between sulphide elimination and acid generation, and to evaluate the operating costs of various separation options.

## Status:

The start of acid generation in tailings is due to the bacteria catalyzed oxidation of the contained sulphides. Most of the acid drainage work to date has looked at the elimination of water and/or oxygen from the tailings, both of which are required to oxidize the sulphides. This project will look at the removal of the sulphides so that the sulphide portion can be treated separately (e.g. separate underwater disposal in a lined containment may become realistic for a significantly reduced volume) and the non-sulphide portion can be disposed of by conventional sub-aerial techniques. It is also considered that this low-sulphide product may be part of a cover over existing tailings.

For logistical and reporting purposes, the program was divided into two parts: preliminary evaluation of mill tailings; and mineral processing. The preliminary evaluation of four tailings samples (elemental analysis, mineralogical analysis, determination of neutralization potential (acid-base accounting and kinetic testing) has been completed and a milestone report is available.

Based on the results from the preliminary mineralogical examination, the contained sulphides for all samples appear to be well liberated and therefore should be amenable to further treatment. It is proposed to evaluate both gravity concentration techniques (spirals, Reichert cones and tables, Knelson and Falcon concentrators) as well as flotation for removal of the sulphides.

Other issues to be covered in the project include recommendations on further work on the most promising applicable techniques.

**Project 3.21.1b:** **Removal of Metals from AMD - Ion Exchange**
**Budget:** **$64,000**
**Sponsors:**
**Teck**
**$10,000**
**Falconbridge** **$ 4,000**
**Ontario** **$30,000**
**Homestake** **$20,000**
**Expenditures:** **$17,000**
**Manager:** **T. Hynes, CANMET**
**Contractor:** **CANMET**

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**Objectives:**

**Assess and demonstrate the applicability of ion exchange to remove selected metals from acidic drainage.**

**Status:**

**Ion exchange resins show great potential for improving the treatment of acid mine drainage. The process of metals removal will significantly lower the metal content of subsequent treatment sludges. This would provide the walk-away closure scenario at a site where acidic drainage is effectively stopped, and the lime treatment plant is shut off. Little to no care and maintenance of treatment sludge ponds would be required.**

**Experiments are now in progress with an actual acid mine drainage solution provided by Homestake Canada. Selected ion exchange resins are being tested for their ability to extract metals from real acid mine drainage solutions. The results so far indicate that the extraction of copper, antimony and zinc are technically feasible from the solution. While copper and antimony can be directly removed from the acid solution, the recovery of zinc requires a partial neutralization to pH 4.5 to eliminate ferric iron from the solution. It is believed that further neutralization to pH 10, as is common practice, may be unnecessary after the ion exchange treatment. This would represent a significant reduction in lime consumption and in the toxicity of the neutralization sludge.**

Further work will aim at obtaining additional data and to address the economical and ecological aspects of the lime neutralization, with and without ion exchange. Other aspects will include studying the removal of other metals, find ways to improve the selectivity and kinetics of the extraction, and make recommendations on pilot scale tests.

**Project 3.22.1:** **Canada-wide Survey of Acid Mine Drainage Characteristics**
**Budget:** **$15,000**
**Sponsor:** ..............................................................................................................
..............................................................................................................
.............................................................................................................. **Ontario**
.............................................................................................................. **$15,000**
**Expenditures:** **$0**
**Manager:** **T. Hynes, CANMET**
**Contractor:** **CANMET**

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**Objective:**

**The prime objective is to create a data bank on the composition, flowrates and seasonal fluctuation of acid mine drainage streams in Canada. This information will be made widely available and will be used to define strategies in improving acidic drainage treatment techniques.**

**Status:**

**Acidic effluent generation from sulphide tailings and waste rock piles will continue long after cessation of mining activities, posing a long-term liability. Lime neutralization is a common treatment practice to neutralize acid and precipitate heavy metals. This methodology is simple and economically attractive, but it produces large volumes of potentially troublesome sludge, may have high maintenance requirements, and may not meet new standards for waste disposal. To improve or replace lime neutralization, new technology applicable to specific sites may be necessary.**

**In 1991, a report was produced for MEND on the technology options available for removing metals from acidic drainage. This report provided some basic information on acidic mineral drainage streams in Canada. Information, although limited, demonstrated the wide range of contaminants in various effluents. In order to obtain an overall view of the problem, it is apparent that a wide database of information on acid drainage characteristics is necessary.**

**A questionnaire is being developed to collate information on:**

a) chemical composition
b) flowrates, sources (e.g., waste rock, tailings seepage, and sample locations)
c) suspended solids content; and
d) seasonal variation in chemical composition, flowrates and suspended solids content.

The final report will be completed in 1994.

**Project 3.31:** **Use of Lime Sludges for Capping**
**Budget:** **$30,000**
**Sponsor:** ..........
..........
.......... **INCO**
.......... **$6,700**
CANMET .......... **$23,300**
**Expenditures:** **$12,000**
**Manager:** **P. Kondos, CANMET**
**Contractor:** **Laurentian University**

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**Objective:**

**The main objective of this project is the examination of modified lime sludge as a capping material for waste rock or tailings.**

**Status:**

**Large amounts of sludge are generated when lime is used in the treatment of AMD before being released to the environment. This sludge is a liability for two main reasons. There is the potential of the heavy metals in the sludge being leached out and released to the environment. Also, the material is voluminous and requires large storage areas. If the lime sludge can be adequately dewatered, it is possible that the sludge could be used in an engineered cover.**

**Inorganic materials when used for capping are susceptible to failure in providing water-tight and air-tight capping because of cracking as the rock or tailings pile settles, or because of desiccation. In this work, it is proposed that lime sludge be used as a filler in an inexpensive elastomeric material which in turn would be used as a capping cement. An elastomeric cement will be designed which will contain a large proportion of sludge in its matrix. Investigation of the compatibility of the plant sludge with elastomer will be undertaken and sludge modification undertaken if required.**

**In 1993, mine sludge has been characterized with respect to its components and interaction with water. Some solid phases of the sludge have been identified. A number of elastomeric compounds have been tested as possible matrix material for sludge solids at various sludge loadings.**

It has been determined that wet sludge solids (86%) can be blended with a number of elastomeric materials.

The next steps are to:

- determine the adhesion characteristics of capping material to typical waste rock; and
- evaluate the effect of adverse conditions on elastomeric material.

The final report will be completed in 1994.

**Project 3.32.1:** Lime Treatment - Process Review and Sludge Stabilization
**Budget:** $60,000
**Sponsor:** ....................................................................................................................................
....................................................................................................................................
.................................................................................................................................Ontario
.................................................................................................................................$30,000
CANMET.................................................................................................$30,000
**Expenditures:** $38,000
**Manager:** K. Mailhiot, CANMET
**Contractor:** SENES Consultants

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Objectives:

The state-of-the-art for chemical treatment of all types of acidic drainage encountered in Canada will be summarized and a reference manual for owners and operators of plants treating acidic drainage from mine sites will be prepared. Recommendations on conducting targeted research and development of lime and other alkali chemical treatment systems will be made.

Also investigations on methods of stabilization and fixation of lime treatment sludges produced from the neutralization of acidic drainage will be completed.

Status:

Lime treatment and sludge stabilization is a high priority area of work defined in the Revised Research Plan. Long-term treatment of acid mine drainage is in essence the main component of the long term liability at many inactive mine sites.

During the two first phases of this project, contacts were initiated with suppliers, researchers, and the mining industry and an information base has been developed regarding current and planned AMD chemical treatment practices. Chemical treatment of AMD, at almost all treatment facilities, is based on the use of lime neutralization and subsequent sludge precipitation. Cooperation received from industrial contacts has been excellent.

A review of technical databases was undertaken. The information received has been reviewed, and standardized summaries are being prepared for selected documents. Considerable technical information is available on lime treatment but scientific evaluations of sludge characteristics and disposal are limited.

The next step will be to review and assess the current state-of-the-art of AMD treatment technology and sludge management practices to identify gaps and make recommendations on research to fill the technology gaps.

The final report will be completed in 1994.

ACTIVE

MONITORING
March 1994

Project 4.3.2: Reference materials
Budget: $28,000
Sponsors:

Environment Canada .......... $26,000
CANMET .......... $ 2,000

Expenditures: $27,300
Manager: B. Godin, Environment Canada/M. Blanchette, CANMET
Contractor: CANMET, Canada Certified Reference Materials Project (CCRMP)

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Objective:

The purpose of this project is to develop a standard material to be used in the prediction testing of the susceptibility of mine waste to develop acidic drainage.

Status:

A standard material will enable the reliable comparison of results obtained internally and by different laboratories evaluating the acid generating potential of rock samples. No commercially available materials currently exist for this purpose. As a first step, approximately 300 kg of processed standard material for ARD static testing will be generated on completion of this project. Formal analysis of the material, to obtain standard values for Net Neutralization Potential (NNP), total sulphur and sulphate, are outside the scope of this project. This is expected to be carried out in 1994 under the Prediction committee through a round robin program (1.16.2).

Approximately 500 kg of material, a non-ore grade, altered biotite feldspar porphyry, from the Noranda Bell Mine in British Columbia has been received. Through the Canadian Certified Reference Material Project (CCRMP) of CANMET, it has been processed to 80% less than 200 mesh by crushing, and grinding and screening. Blended to ensure homogeneity, the processed material has been bottled under nitrogen in 3429 100 gram units and the glass bottles sealed in foil pouches, again under nitrogen to eliminate any further oxidation of the sulphides.

Grab samples of the material have been analyzed for total sulphur, sulphate, and neutralizing potential to obtain a preliminary value of the material's net neutralizing potential (NNP). From preliminary results the material appears to be an acid consumer, containing 0.36% sulphur and having an NNP of approximately +40 kg $CaCO_3$/t. Characterization of magnesium and calcium carbonate as well as homogeneity testing (iron, sulphur) of the bottled material are still required to complete this project. The material, NBM-1, will be made commercially available through the CCRMP and is also expected to be used to develop protocols for static prediction test through the MEND program (1.16.2).

ACTIVE

MONITORING
March 1994

| | | |
|---|---|---|
| Project 4.5.1: | Field Methods Manual - Waste Rock | |
| Budget: | $80,000 | |
| Sponsor: | | |
| | | |
| | | CANMET |
| | | $24,000 |
| | AECB | $10,000 |
| | INCO | $25,000 |
| | Homestake Canada | $10,000 |
| Expenditures: | $24,000 | |
| Manager: | K. Scissons, AECB | |
| Contractor: | SENES Consultants | |

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Objective:

A handbook for waste rock sampling will be produced which will provide guidance to a broad spectrum of the mining industry, consultants, and regulatory personnel as to the type of data required, the available sampling techniques, and suggested methodologies during various stages of mine life.

Status:

The scope of work was split into two phases to address concerns raised by the MEND Management committee. Phase I was contracted and completed in 1992, providing a draft waste rock sampling manual which is a comprehensive review of techniques for waste rock sampling and characterization. Parameters including permeability, porosity, moisture content, grain size, flow and infiltration, biological activity, meteorology, and temperature are covered.

The second phase of this program was initiated in 1993. The proposed work involves a number of distinct deliverables:

- A finalized version of the waste rock sampling manual;
- A position paper outlining a recommended approach to sampling;
- An experts' workshop and associated proceedings; and
- A handbook for waste rock sampling.

A thorough review of the Phase I draft sampling manual is almost completed. Revisions have been based on an external survey of academia, contractors, industry and government. The final version is expected to assess the techniques listed according to comfort level, resultant data, estimated cost, and reproducibility. An experts' workshop is being organized for March 1994, and should involve a minimum of 10 panelists as well as observers. Prior to the workshop a position paper will be developed outlining a recommended approach to waste rock sampling. This paper will be the basis of the workshop, and will be finalized at that time. The workshop will involve representatives from industry, regulatory agencies, consultants, and those involved in waste rock predictive modelling. The overall project is scheduled to be completed in 1994.

ACTIVE

MONITORING
March 1994

**Project 4.5.3:** ARD Technical Guide Revision - Monitoring Section
**Budget:** $50,000
**Sponsor:** ..........................................................................................
..........................................................................................
..........................................................................................CANMET
..........................................................................................$50,000
Environment Canada ..........................................................................$ 3,700
**Expenditures:** $33,700
**Manager:** E. van Huyssteen, CANMET
**Contractor:** EVS Environment Consultants

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Objective:

The objective of the project is to produce a monitoring manual and a complete revision of the monitoring chapter of the B.C. Draft Acid Rock Drainage Technical Guide.

Status:

The B.C. Draft Acid Rock Drainage Technical Guide was completed in 1989. Since that time various literature reviews and monitoring projects have been sponsored to address deficiencies identified in the guide monitoring chapter. The first output of this project will be a monitoring guide to include the following: principles, concepts and restrictions in developing monitoring programs; monitoring technology and equipment installation and maintenance; data management, including QA/QC; and advantages and limitations of the techniques as they are applied to various mining and downstream environments.

A draft final report has been submitted, reviewed in detail and revised. The report describes the principles, concepts and limitations of developing a monitoring program. A description of the ARD process, including the mine components involved, is given. Sampling techniques and parameters used to monitor ARD sources, pathways and impact are addressed. General guidelines for data management and the development of a working program are presented. The conceptual structure for developing an ARD monitoring manual has been divided into 12 steps. These steps include such areas as: initial characterization; establishment of monitoring needs; development of objectives; where, when, and what to monitor; sample number;

monitoring techniques; cost benefit analysis; and data analysis and follow-up. These 12 steps are reflected in the structure of the manual. A glossary of terms and fact sheets for specific parameter assessments (such as salinity, dissolved oxygen, sulphate, etc.) are attached as appendices.

Final revisions are currently being made to the manual and they are expected to satisfy the requirements for the first deliverable. The second project deliverable is a condensed version of the manual. Once accepted, this latter document is expected to replace the monitoring chapter of the B.C. Draft Acid Rock Drainage Technical Guide.

ACTIVE

**MONITORING**
**March 1994**

| | | |
|---|---|---|
| **Project 4.6.1:** | **Assessment of Geophysical Monitoring Methods** | |
| **Budget:** | **$118,000; 1992/93($83k), 1993/94($35k)** | |
| **Sponsor:** | | |
| | | |
| | | **Ontario** |
| | | **$38,000** |
| | **CANMET** | **$38,000** |
| | **INCO** | **$54,558** |
| **Expenditures:** | **$130,560** | |
| **Manager:** | **E. Kustan, INCO** | |
| **Contractor:** | **INCO Exploration & Environmental Control** | |

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**Objective:**

**To demonstrate and document the application of four geophysical methods to detect and assess subsurface migration of acid mine drainage.**

**Status:**

**For active as well as non-active sites, effective monitoring techniques are needed which are cost-effective. Because AMD investigations have traditionally relied on surface sampling and drilling and sampling of the subsurface, they can be expensive and slow. In suitable environments geophysical methods offer the potential for rapid nonintrusive mapping of significant AMD problems.**

**The assessment of geophysical methods is nearing completion and the report will be available in 1994. The investigation has focused on electrical and electromagnetic geophysical applications since these methods have the potential to directly detect and map sulphides, areas of active chemical oxidation, and acidic seepage. It is believed that their application will offer an immediate benefit to the mining industry in that they can be used to quickly and inexpensively map the extent of groundwater contamination and the sulphide source of AMD.**

**The research has been carried out at two sites in the Sudbury area. Due to the low background conductivities and the high conductivities of AMD, the electrical and**

electromagnetic geophysical methods were able to detect even small amounts of AMD in groundwater in first time surveys. The work carried out suggests that similar AMD plumes should be detectable at least near their source in most Canadian environments. It is emphasized however that geophysical methods should not be used in isolation. Because they do not uniquely identify the source of anomalies they should be used in conjunction with focused drilling and sampling.

A general recommended sequence for the use of electrical or EM methods in AMD site investigations will be outlined in the report. As well, recommendations will be made regarding areas for further development and application. The project is expected to be completed in 1994.

ACTIVE

**MONITORING**
**March 1994**

**Project 4.6.3:** Remote Monitoring Techniques - Review
**Budget:** $60,000
**Sponsor:** ..........................................................................................................
..........................................................................................................
..........................................................................................................CANMET
..........................................................................................................$29,200
Ontario..........................................................................................$29,200
**Expenditures:** $9,800
**Manager:** M. Blanchette, CANMET
**Contractor:** Paterson, Grant & Watson Geomatics

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Objective:

To identify and evaluate available remote monitoring or sensing techniques and to address the applicability of these techniques for use at acid-generating or potentially acid-generating sites.

Status:

The scope of work is defined to include all non-intrusive remote sensing and geophysical methods that are being, or could be, applied to the detection and/or monitoring of AMD. The database search is nearly complete and more than one thousand references have been listed or scanned. A full bibliography will be incorporated in the final report. Specific individuals have also been contacted to provide either unpublished information or further contacts.

A two part questionnaire has been prepared to solicit additional information. Part 1 involves remote sensing while Part 2 of the questionnaire considers geophysics. A comprehensive mailing list was compiled in order to contact all appropriate international agencies as well as industrial personnel. Analysis of the questionnaire results will assess: the level of activity; methods and techniques; applications and limitations; available literature both published and unpublished; and other sources of information.

Currently, the various techniques identified, through the literature review and questionnaire, are being evaluated based on a specific set of criteria. In-depth evaluation of a number of specific techniques will be done using a series of case studies. Preparation of case histories will depend on the data sets available. A study of the data sets, as well as an assessment of what can be gained by enhancing and manipulating these data sets with available software, will be made.

The end result of the project will be a compendium, in handbook form, of remote monitoring technologies for acid mine drainage. Identification of current gaps and recommendations for further development of one (or more) specific technique will be based on the current state of the art. Further development in one or more areas of remote monitoring is expected to be considered and initiated by the Monitoring committee based on the recommendations from the current study.

ACTIVE

MONITORING
March 1994

**Project 4.6.4:** Piezocone Field Test
**Budget:** $26,650
**Sponsors:**..............................................................................................................

..............................................................................................................................

.......................................................................................................................Ontario

.......................................................................................................................$17,650

INCO.........................................................................................$ 9,000

**Expenditures:** $12,000
**Manager:** M. Blanchette, CANMET
**Contractor:** University of British Columbia, ISRG

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Objective:

The objective of this study is to demonstrate the ability of existing in situ testing technology, specifically resistivity piezocone technology, to carry out characterization of tailings and soils with respect to ARD and related phenomenon.

Status:

With any subsurface assessment of environmental conditions, the method of site characterization dictates the quality of the information obtained. In situ testing, using sophisticated instrumented mechanical devices, offers a technically superior and cost effective alternative for site characterization.

An assessment of INCO's central tailings site in Copper Cliff, Ontario has been carried out by the In-situ Research Group (ISRG) of the University of British Columbia. The work has been carried out in conjunction with studies currently underway through INCO and the Waterloo Centre for Groundwater Research. Data from these studies will be incorporated in assessing the monitoring technology. A detailed geotechnical and hydrological analysis of all soundings is being carried out, in addition to an assessment of the resistivity data. Soundings varied from 2 to 42 meters in depth.

UBC ISRG utilizes a two-step approach for groundwater assessment which combines resistivity mapping and discrete groundwater sampling. A continuous record of resistivity with depth is measured with the resistivity CPTu (RCPTu). This test allows measurements of resistivity to be made from a separate module located behind a standard piezometer cone. The RCPTu identifies zones where values of resistivity differ from background values. These areas are then further evaluated with the BAT groundwater sampling system. The BAT system is used for measurement of pore fluid properties. As with the RCPTu, the equipment can be hydraulically pushed down into tailings and soils. Discrete pore water samples can then be taken.

The report, which will be completed in early 1994, is expected to describe the piezocone and BAT technologies as well as their relative advantages and disadvantages with respect to more traditional monitoring technologies.

**Project 4.8.2:** **Sediment Sampling Probe Field Application**
**Budget:** $51,000
**Sponsor:**

| | |
|---|---|
| CANMET | $17,038 |
| Falconbridge | $12,000 |
| INCO | $ 5,000 |
| Ontario | $17,037 |

**Expenditures:** $19,600
**Manager:** C. Weatherell, CANMET
**Contractor:** AECL

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**Objectives:**

To evaluate the use of the sediment probe as a method for determining the location of submerged AMD contaminated groundwater discharge zones into lakes, rivers and other waterbodies.

**Status:**

AECL has developed a method for locating and measuring groundwater discharges which are often obscured by the presence of overlying surface water. The technology may allow accurate and inexpensive environmental monitoring to be conducted at specific locations where environmental impact is occurring or is likely to occur.

An electrical conductance, bottom-contacting probe was towed behind a slowly moving boat over more than 28 line kilometres of lake and river bottom. In the fall of 1992 and in June, 1993 electrical conductance surveys were done in two general areas: between the public access and the lake outlet of Kamiskotia Lake; and in the Little Kamiskotia river from the lake outlet to about 3 kilometres downstream. The Kamiskotia Lake is about 25 km northwest of Timmins, Ontario. A laser positioning system was used on the lake but could not be used on the river due to the forested banks and adjacent swamps. As well, walking surveys allowed access in areas of water less than 0.3 meters deep. Shoreline surveys using a conductivity walking stick connected to a portable conductivity meter were performed along the eastern lake shore.

The probe reconnaissance was used to target several areas of possible leachate discharge. These were studied quantitatively in order to evaluate the utility of the probe and to provide site-specific information. Discharges were confirmed by direct measurement of flux seepage meters or by measuring upward gradients, moderately high hydraulic conductivities or solute chemistry. Discharges ranged from 677 - 13,800 µs/cm and from 4.8 - 6.9 pH. For a variety of reasons discussed there is little correlation between pH and conductivity. Analyses of major ions, metal, and isotopes will aid in distinguishing the underground sources.

The report is being completed and will be made available in 1994.

ACTIVE

TECHNOLOGY TRANSFER
March 1994

**Project 5.2.1a-c:** Communications Plan - CIMM Lectures, Brochure, TV Series
**Budget:** $5,000
**Sponsors:** ........................................................................................................................
........................................................................................................................
........................................................................................................................CANMET
........................................................................................................................$5,000
**Expenditures:** $0
**Manager:** K. Mailhiot, CANMET
**Contractors:** In house, CANMET Secretariat

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**Objectives:**

To inform key audiences about the issue of acidic drainage and the new affordable technologies being developed to solve the problem, and about MEND being a co-operative program involving governments and industry working together toward practicable, affordable solutions to the problem.

**Status:**

In March 1992, the Communications Task Force appointed by the Board of Directors recommended that a communication expert by hired to aid in implementing the proposed communications strategy.

A Communications Workshop was held in June 1993 to identify MEND business strategies, targeted audiences, communications strategies and communications vehicles. Priorities were set in terms of primary audiences and an agreement was reached on an action plan. Because of limited resources allocated to communications, it was decided to focus the efforts, and to developed a phased action plan. To address the targeted audiences, the communications vehicles recommended were:

- The CIMM Distinguished Lectures Series. MEND would be the subject of one or more lectures;
- A print brochure to convey basic information about AMD and the technologies being developed to solve the problem;

- A series of television programs on the Mining Industry, prepared by the Mining Association of Canada and ISTC; and

- A video, recognizing the importance of "show and tell".

The Technology Transfer appointed a Communications sub-committee to ensure the implementation of the action plan.

ACTIVE

## TECHNOLOGY TRANSFER

March 1994

**Project 5.6.2:** Third International Conference on the Abatement of Acidic Drainage
**Budget:** $15,000
**Sponsors:**

| | |
|---|---|
| Association Minière du Québec | $4,000 |
| Ontario | $5,000 |
| CANMET | $3,000 |

**Expenditures:** $12,000
**Manager:** K. Wheeland, Environmental Coordinator
MEND Secretariat

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**Objective:**

MEND will cosponsor with the United States Bureau of Mines, the Third International Conference on Abatement of Acidic Drainage.

**Status:**

To promote communication in the areas of acidic drainage and land reclamation, two major conferences planned for 1994 have been combined into a joint conference which will be held in Pittsburgh in April 1994.

The total attendance is expected to exceed 1000 people, out of which 600 to 700 people will be concerned with Acidic Drainage. Eighty-five refereed papers, 75 posters and 5 training courses will deal with Acid Mine Drainage. MEND participants and contractors are expected to contribute about 30 refereed papers and 10 posters. There will be a special panel discussion on international acid drainage research chaired by MEND.

As a cosponsor, MEND participates in planning sessions, reviewing papers, chairing sessions and presenting papers. This conference is a good opportunity for MEND members to exchange new information with others working in the field of acidic drainage.

The proceedings will consist of refereed papers (oral and poster sessions) by MEND participants and other leading researchers.

**The Fourth Conference on the Abatement of Acidic Drainage is tentatively planned for Vancouver in 1997 and will be hosted by MEND.**

ACTIVE

TECHNOLOGY TRANSFER
March 1994

**Project 5.7.1:** MEND Newsletter
**Budget:** $3,000
**Sponsors:**
CANMET
$3,000
**Expenditures:** $3,500
**Manager:** K. Mailhiot, CANMET
**Contractor:** In-House, MEND Secretariat

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**Objective:**

To keep MEND Participants informed of progress on current efforts to find workable and economic solutions to the significant environmental liability posed by Acid Mine Drainage.

**Status:**

To ensure that the objectives of MEND are achieved, results of the research work on acidic drainage have to be transferred to users. Regular publication of a Newsletter is an effective way to inform MEND participants on research progress. It also promotes communication among members and advertises the existence and purpose of the MEND program.

Two issues have been published and distributed to over 600 people in 1993. Information was given on technical projects in the area of Prevention & Control and Monitoring, people involved in the Program, recent publications, upcoming events, and special features on what is MEND. Databases on AMD and provincial workshops held in 1993 were also summarized.

The Newsletter will continue to be published in 1994 and MEND will expand the distribution.

**Project 5.8.1:** Economic Evaluation of MEND-developed Technology
**Budget:** $40,000
**Sponsors:**
Ontario
$40,000
**Expenditures:** $0
**Manager:** J. Salley, CANMET
**Contractor:** To competitive bid in early 1994

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**Objective:**

The project will determine the base cost of prevention, control and treatment of acid mine drainage with existing technology, and will develop a protocol for economic evaluation of existing and emerging technologies being developed by MEND.

**Status:**

In 1992, the MEND Management Committee recommended the development of a framework that would provide an "economic evaluation of technology for prevention, control and treatment of AMD".

The work requirements defined for this project are to:

- Review existing and emerging technologies that prevent, control and treat acidic inage;
- Estimate as closely as possible the aggregate cost of currently-applied technology to l with prevention, control and the treatment of acid mine drainage in Canada;
- Provide an updated estimate of the current financial liability to the Canadian mining ustry and to the Canadian public through their governments caused by acid mine drainage.
- Develop an easy-to-use software-based protocol for the economic evaluation of ting and emerging technologies that prevent, control and treat acid mine drainage; and

- Using the new protocol, provide examples to demonstrate the financial implications arious aspects of dealing with acid mine drainage and recommend emphases for research that would lt in the most liability reduction.

A method of economic evaluation will contribute to a better knowledge of the cost of dealing with acidic drainage in Canada.

A Request for proposals was prepared and a contract will be awarded in early 1994. The work is expected to be completed in 1994.

ACTIVE

## NEW IDEAS & INNOVATION

March 1994

**Project 6.1:** New Ideas Solicitation - Round 1
**Budget:** $162,000
**Sponsors:**

| | |
|---|---|
| CANMET | $30,000 |
| DIAND | $ 9,200 |
| Teck | $20,000 |
| INCO | $10,000 |
| Lac | $10,000 |
| Noranda | $55,000 |
| HBM&S | $15,000 |
| Ontario | $20,000 |
| Québec | $20,000 |
| AMMQ | $10,000 |

**Expenditures:** $200,000
**Manager:** K. Wheeland, Noranda Technology Centre
**Contractors:** Various

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**Objective:**

The objective of New Ideas is to solicit and develop new ideas and innovation that will provide technology to significantly reduce the cost of preventing, controlling and treating acid mine drainage.

**Status:**

In response to the first solicitation of projects, focused primarily at Canadian Universities, ninety proposals were received. The task force reviewed and evaluated all proposals. The proposals were evaluated on the potential for development of technology that would be: inexpensive and long lasting; broadly applicable across Canada; different from currently used methods of prevention and control; and/or result in significant cost reduction of implementing known technology. Thirteen proposals were accepted for funding. For each of these projects, champions were identified and funding was made available.

The status of the thirteen projects is given in Table 18 below. Ten out of 13 projects are completed. The Modified Clay and Selective Ion Exchanger projects will be continued for a second "proof-of-concept" stage. The US Research Survey has provided assurance that current MEND projects are not duplicating work in the United States, and provides leads to new Technology. The Permafrost report provides the needed background for a focussed project in the Prevention and Control committee program in 1993 or 1994. The Critique of Japanese AMD Research summarizes some interesting remedial and treatment technology at an old pyrite mine in Japan. In addition to providing a Japanese linage to MEND, a project on the removal of metals before lime treatment by ion flotation will be considered under New Ideas in 1994.

Although the percentage of projects initiated based on the 90 proposals received in 1992 was not high, the Task Force agreed that the wide spectrum of ideas submitted confirmed that there was considerable interest in solving the problems caused by acid mine drainage. All of the proposals received had a high degree of technical validity. Most of the rejected proposals were refused because the ideas were either uneconomic or the idea had been tried before. The New Ideas program did result in the involvement of new researchers and entrepreneurs in the area of acid mine drainage, and many continue to participate.

Table 18: New Ideas Projects: Results from Round 1

| Project | Status | Results |
|---|---|---|
| #0 U.S. Research | Complete | Research identified for follow up by MEND. |
| #01 Permafrost | Complete | Permanently frozen wastes will not produce AMD. But permafrost can only be assured under deep cover in northern zones. Prevention and Control committee considering further work. |
| #05 Wax Cover | Ongoing | Results encouraging. Awaiting final report. |
| #15 Chelating Ribbons | Complete | Unsuccessful. No further work planned. |
| #17 Modified Clay | Complete | Promising results. Second proof-of-concept stage proposed for 1994. |
| #28 Artificial Hardpan | Complete | Technology appears uneconomic |
| #31 Ion Exchange Resin | Complete | Promising results. Second proof-of-concept stage proposed for 1994. |
| #58 Phosphate Coating | Incomplete | Awaiting final report. |
| #65 Passivation | Complete | Unsuccessful. No further work planned. |
| #69 Waste Comingling | Incomplete | Benefits questionable. Awaiting final report. |
| #73 Japanese Tech. | Complete | Promising technology leads being investigated |
| #83 Chelating/Filtering | Complete | Technology unsuccessful. No further work planned. |
| #90 Polymer gels | Complete | Technology unsuccessful. |

# APPENDIX E

## Recommended Projects

| Number | Titles: |
|---|---|
| 1.12.1b | DBARD - DataBase for Acid Rock Drainage: Continued Compilation of AMD Prediction Data |
| 1.13.1 | Climatic Controls of Acid Generation and Metal Leaching: Literature Review |
| 1.14.3 | Mine Doyon: A Comprehensive Review |
| 1.16.2 | Prediction Test Standard Material: Interlaboratory Program for Characterization of the ARD Standard Material NBM-1 |
| 1.19.2 | Evaluation of Scaling: Chemical Prediction Test Results from Bench to Field |
| 1.21.2 | Laboratory and Modelling Studies of Pyrrhotite Oxidation |
| 2.11.5 | Shallow Water Covers - Equity Silver |
| 2.11.9 | Underwater Disposal Sites - Design Criteria |
| 2.12.1 | Man-made Lakes Disposal Sites - Louvicourt Project |
| 2.13.2b | Monitoring of the Flooded Solbec-Cupra Tailings Site |
| 2.13.3 | Flooding of Existing Tailings Sites - Falconbridge |
| 2.21.3 | Peer Review of Waite Amulet and Heath Steele Soil Covers |
| 2.21.4 | Protocols for Engineered Soil Covers over Tailings and Waste Rock |
| 2.23.3 | Porous Envelope Surround Disposal Method - Falconbridge |
| 2.35.2 | Lysimeter Evaluations of Cover Alternatives - Noranda |
| 2.36.1 | In-Pit Disposal - Case Studies |
| 2.36.2 | In-pit Underwater Disposal of Oxidized Waste Rock |
| 2.45.2 | Separation of Sulphides from Mill Tailings - Case Studies |
| 3.14.1 | Review of Passive Systems for Treatment of AMD |
| 3.21.3 | Removal of Metals - Pilot Tests |
| 3.41.1a | In Situ Treatment of AMD |
| 4.6.1b | Geophysical Monitoring Techniques - Further Application and Development |
| 5.1.2d | Communications Plan - Video on AMD/MEND |
| 5.4.2 | AMD Handbook |
| 5.6.3 | Fourth International Conference on Abatement of Acidic Drainage |
| 6.2 | New Ideas Solicitation - Round 2 |

**Project 1.12.1b:** DBARD - DataBase for Acid Rock Drainage: Continued Compilation of AMD Prediction Data
**Budget:** $40,000
**Sponsor:** ..........................................................................................
British Columbia ..........................................................................................$20,000
CANMET..........................................................................................$20,000
**Manager:** To be determined
**Contractor:** University of British Columbia: Chair in Mining and the Environment

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**Objective:**

This project will develop the existing database for acid rock drainage prediction data, DBARD, through:

- additional input of selected available static and kinetic test data;
- further development and user accessibility of the software; and
- ongoing maintenance and distribution.

**Fit With Program:**

The database, DBARD, was developed over the last two years to accept, store and retrieve relevant data from acid prediction testwork, including data from one-time or repetitive laboratory experiments and field tests. Version 1.0 of DBARD was a simplistic database with rudimentary routines for data entry which was not released. The database was greatly expanded in version 2.0 with improved data handling and editing, but little data was actually entered.

Since April, 1993, the database has resided at the University of British Columbia under the auspices of the Chair in Mining and the Environment. During this time the focus was on data input. The database now contains information, although not comprehensive, on mine component characterization and AMD prediction for 119 mines in British Columbia (1.12.1a). Over the next year, selected data input from the rest of Canada, and internationally, will ensure that a wide range of different and comprehensive prediction datasets are included. Ongoing updates to the software will be carried out as required with associated modifications to the User's Manual. Direct access to the database through Internet is also being considered.

**Projected Output:**

DBARD is an important depository for the large volume of AMD prediction test data. The

**database will become a useful tool to improve the understanding of AMD, the utility of current prediction tests and interpretive methods, comparisons on a site-to-site basis, and to facilitate waste management decisions. Deliverables for the upcoming year will include a complete set of database files, an updated User's Manual, and a report of the work carried out with respect to information collection, its dissemination and any future recommendations.**

| | |
|---|---|
| Project 1.13.1: | Climatic Controls of Acid Generation and Metal Leaching: Literature Review |
| Budget: | $50,000 |
| Sponsor: | To be determined |
| Manager: | To be determined |
| Contractor: | Competitive bidding |

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**Objective:**

**This project will compare and contrast the rate of sulphide oxidation and development of acid mine drainage for deposits located in different climatic zones (ie. continuous permafrost to temperate) within Canada, initially through a review and assessment of applicable field and laboratory work currently available.**

**Fit With Program:**

**Sulphide oxidation is the primary cause of AMD and the frequently associated metal contamination problem. Just as in the weathering of rock-forming minerals, local climate greatly affects the rate and extent of oxidation and thus also the development of AMD. While both the rate of chemical reactions and the role of microbial mediation in the sulphide oxidation process are greatly reduced under northern conditions, AMD occurs regardless of latitude. A few studies to date have simulated average annual precipitation and altered temperature settings of kinetic leaching experiments. However, there is still a general lack of understanding of the influence of climatic conditions on the generation of AMD. This was underlined at a 1992 Workshop sponsored by the Department of Indian and Northern Affairs in Yellowknife. A detailed study is therefore considered necessary to clarify the dominant parameters controlling AMD and associated metal contamination under different climatic conditions, particularly those observed in northern Canada.**

**A comparison of the rate of oxidation in sedimentary exhalative massive sulphide (SEDEX) deposits located in different climatic zones (continuous permafrost, discontinuous permafrost, alpine permafrost, and temperate) has been proposed. SEDEX deposits are both mineralogically simple, and as outlined in project 1.32.1, prone to development of AMD. Prior to detailed site comparisons and any long-term field programs, a review of any currently available information and studies regarding climatic effects is recommended. Detailed recommendations, based on the review, regarding appropriate sites and required field and laboratory work, will focus future work.**

**Projected Output:**

**The overall output of the proposed program is the identification of the dominant mechanisms operative in deposits under varied climatic conditions. This will allow recommendations for appropriate strategies to assess or predict AMD potential in northern climates.**

**Project 1.14.3:** **Mine Doyon: A Comprehensive Review**
**Budget:** **$40,000**
**Sponsor:** ..........................................................................................
..........................................................................................
..........................................................................................CANMET
..........................................................................................$20,000
Quebec ..........................................................................................$20,000
**Manager:** To be determined
**Contractor:** Competitive bidding

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**Objective:**

A large and detailed research program on the south waste rock dump at Mine Doyon has been carried out over the past three years through the University of Laval in conjunction with the mine personnel. The objective of this project is to complete a technical review of the monitored data collected and the associated site assessment made to date prior to carrying on with further studies.

**Fit With Program:**

A detailed, long-term field program has been carried out on the south dump at Mine Doyon over the last three years (1.14.1, 1.14.2). Monitoring data collected over this time has included climatic, biological, geochemical, hydrological and physical parameters within the dump. From the information collected, simulation capabilities are being developed such as:

- geochemical (eg. rates of oxidation and storage of secondary products);
- physical (eg. heat production and temperature profiles); and
- hydrologic (eg, infiltration and residence times).

As one of the most studied waste rock piles in Canada, the 21 million tonne dump provides an excellent opportunity for further development of predictive capabilities. The committee is recommending a technical review by an independent expert(s) before additional work at Mine Doyon is defined. The review will provide a summary of the work done to date, and through recommendations for future priorities, it will ensure the quality and completeness of the field data collection and their interpretation as they relate to the prediction of AMD from waste rock dumps.

**Projected Output:**

**The deliverable of this project will be a report which will include a critical review of all project reports to date related to Mine Doyon. The report will include specific recommendations for further research, monitoring or other work, in the context of current waste rock prediction capabilities.**

**Project 1.16.2:** Prediction Test Standard Material: Interlaboratory Program for Characterization of the ARD Standard Material NBM-1
**Budget:** $20,000
**Sponsor:** ..............................................................................................................................................................
Environment Canada ......................................................................................$10,000
CANMET.............................................................................................$10,000
**Manager:** H. Steger, CANMET
**Contractor:** CANMET: Canadian Certified Reference Materials Project (CCRMP)

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Objective:

This project will extend the characterization of the standard material, NBM-1, for use as a standard material for acid rock drainage static prediction tests.

Fit With Program:

There are a variety of static tests that have been documented (1.16.1bc) and are used to predict the potential for acid generation or neutralization of mine waste material. Currently however, there is no standard material that will allow comparison of static test results within and between laboratories, or for the comparison of various protocols.

Through a Memo of Understanding between Environment Canada and the Canadian Certified Reference Materials Project at CANMET, a non-ore grade pit rock from the Noranda Bell Mine in Granisle British Columbia has been processed to produce over 3000 100gr bottles of NBM-1 (4.3.2). The material, processed to less than 200 mesh, has been bottled and sealed under nitrogen in foil pouches to protect against oxidation. The homogeneity with respect to iron and sulphur has been confirmed and carbonate concentrations determined.

After identifying the methods, elements and other significant parameters for ARD static prediction techniques through a survey, an interlaboratory measurement program will be conducted. Analyses for a minimum of total sulphur, sulphate, acid generating potential, and net neutralization potential (NNP) will be requested from participating laboratories. Approximately 20 laboratories will be sought to participate under arrangements similar to other CCRMP analyses programs. The results from the program (NNP, total sulphur etc.) will

**be statistically analyzed and an evaluation of the methods used will be performed.**

**Projected Output:**

**A report will be prepared containing all results for the ARD static prediction tests, statistical analysis of all results, method summaries and conclusions. The report, or a summary thereof, and a Certificate of Analysis will be provided with each bottle of NBM-1 obtained thereafter.**

**Project 1.19.2:** **Evaluation of Scaling: Chemical Prediction Test Results at Bench, Pilot and Field Scales**
**Budget:** $21,000
**Sponsor:** ........................................................................................................................
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Environment Canada
.......................................................................................................................................$21,000
**Manager:** B. Godin, Environment Canada
**Contractor:** Competitive bidding

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**Objective:**

The current approach in setting up tests for evaluation of ARD material will be assessed and an evaluation of the validity of current practices in scaling between bench, pilot and field scale for spatial, temporal, physical, chemical and biological processes involved in acid generation will be completed.

**Fit With Program:**

It is readily apparent that the ability to determine the applicability of small scale tests to large dumps is limited by the lack of quantitative information of the significance of various processes in controlling the chemistry of water emerging from smaller scale dumps (1.19.1). Also, tests for acid rock drainage prediction (eg. humidity cells, column tests) as well as small scale treatment systems are used frequently to determine the success or failure of a particular approach. Little examination of the precision in the analysis and the size effects that may be significant at a smaller scale has been carried out. Appropriate scaling between the physical, chemical and biological processes is important.

Often, certain effects occur only after reaching a critical point. It is not unreasonable to believe that scaling of waste rock experiments may not be constant throughout a continuum of volume and time, and that parameters may be affected by such scaling laws. A better understanding of these scaling 'laws' could result in the application of non-field scale experiments with increased confidence.

**Projected Output:**

**The project will result in a report on the procedures to use in scaling tests, experiments, and treatment systems. An evaluation of the precision of instrumentation and associated sensitivity analyses on selected parameters will determine the predictability of the data resulting from a scale change. Empirical data will be used to validate conclusions.**

**Project 1.21.2:** Laboratory and Modelling Studies of Pyrrhotite Oxidation
**Budget:** $100,000
**Sponsor:** ..............................................................................................................................
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..........................................................................................................................CANMET
......................................................................................................................$50,000
Ontario............................................................................................$50,000
**Manager:** To be determined
**Contractor:** University of Waterloo

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**Objective:**

The controls of pyrrhotite oxidation kinetics will be studied under environmental conditions representative of waste disposal with special emphasis on the acquisition of data that are required to model dynamic tailings oxidation in the environment using existing models, and enhanced versions based on this research.

**Fit With Program:**

Pyrrhotite is a significant sulphide at many base metal mines across Canada and has been generally ignored in favour of the traditional focus on pyrite that dominates sulphide wastes associated with coal mining in the United States. It is evident from the small number of studies that pyrrhotite oxidation differs significantly from pyrite. Yet the importance of pyrrhotite's oxidation kinetics in the production of acid is not well understood, and fundamental data on the oxidation of this mineral, required to predict oxidation rates in the field, is greatly lacking. A practical study of pyrrhotite oxidation that will fill gaps in current knowledge has been outlined based on critical parameters identified in previous investigations and modelling efforts (surface area, oxygen concentration, solution pH, temperature and bacterial catalysis etc.).

Modelling can be used to examine the consequences of oxidation under various physicochemical conditions. The existing uncertainties in the database for pyrrhotite and the lack of validation under controlled oxidation scenarios diminish this usefulness. A kinetic model for pyrrhotite oxidation will be developed based on laboratory data and taking into consideration intermediate products of oxidation. Apart from the parameters above, the potential interactions with pyrite and the effects of ferric hydroxide solids as a reservoir of the

**oxidant, ferric iron, will be studied. Column studies will then be conducted to simulate the unsaturated zone in a tailings environment. The results of the column work will provide validation of models for short-term behaviour.**

**Projected Output:**

**The project will provide needed fundamental information on the oxidation of pyrrhotite that should be immediately applicable to the prediction of acid generation rates in sulphide tailings. This will also provide greater confidence in predictions that relate not only to existing field conditions but also to waste management scenarios for reduction of sulphide oxidation.**

| | | |
|---|---|---|
| Project 2.11.5: | Shallow Water Covers - Equity Silver | |
| Budget: | $80,000 | |
| Sponsors: | Placer Dome | $ 40,000 |
| | CANMET | $ 40,000 |
| Manager: | J. Robertson, Placer Dome | |
| Contractor: | To be determined | |

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Objective:

The objective of the project is to verify the assumptions made for tailings pond decommissioning at the Equity Silver site. Such an evaluation will validate the engineered design criteria used for the close-out scenario at the site.

Fit with Program:

The Equity Silver mine located near Houston, B.C. ceased operations in January 1994. At the time of closure about 80 million tonnes of waste rock will have been excavated from the open pit and placed into waste dumps. The tailings resulting from the ore processing have been submerged underwater in a shallow lake impoundment which contains approximately 33 million tonnes of tailings and covers an area of about 120 hectares. The tailings are estimated to contain between 4 and 5% pyritic sulphides.

Decommissioning of the shallow lake tailings impoundment was designed as a "closed circuit" system to ensure that acceptable downstream water quality standards are met. A treatment system is in operation and will be required for the foreseeable future to treat the excess annual supernatant (e.g. precipitation) but eventually it is hoped that a flow through system can be established once the metal levels drop below discharge requirements (dilution rate of 10% per year by precipitation expected). At this point no treatment would be required and the supernatant would be discharged directly to the environment.

The Equity Silver tailings pond is one of the first sites to close that has used the concept of water covers (cover of 1 to 1.5m depth) over fresh tailings. Assumptions were used during the design of the impoundment. This project is an opportunity to return to the closed-out site and complete an engineered evaluation on the effectiveness of shallow water covers. A monitoring program will be completed to study the water balance (e.g. seepage, water depth, extreme flood conditions) surface and groundwater chemistry, hydrology, meteorological (e.g. precipitation,

**evaporation), wave action (e.g. tailings mobilization, erosion) and ice erosion.**

**Projected Output:**
**Water cover should minimize the transport of oxygen, and subsequently limit acid generation. A systematic evaluation of key design variables in a closed-out mine and a comparison to the design criteria will yield either a verification of appropriate criteria or revised more applicable criteria. This is one case study which will assist in the development of a design and operating manual for subaqueous tailings disposal.**

**Project 2.11.9:** Underwater Disposal Sites - Design Criteria
**Budget:** $50,000
**Sponsors:** Placer Dome, HBM&S, CANMET
**Manager:** J. Robertson, Placer Dome
**Contractor:** To be determined

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**Objective:**

The final general objective of the evaluation of existing disposal sites is the development of criteria for the use of this method for general disposal of reactive tailings. Such criteria would be applicable to new projects as well as existing sites with acid drainage problems.

**Fit with Program:**

At the request of the MEND Board of Directors, a scientific and technical review of all aspects of the work conducted was completed in late 1992. The completion of the peer review (2.11.1d) and preliminary discussions/presentations made to regulatory personnel provided positive feedback on the merits on the use of subaqueous disposal to control reactive materials. Consequently further research work proceeded to provide additional information needed to support the application of this method.

A planning team of technical/scientific experts met in January 1993 and outlined a study program which incorporated the recommendations made in the review. Two lakes were selected (2.11.3 - Anderson and 2.11.4 - Buttle) to continue the field program and work has been undertaken to obtain additional data. Companion studies include technical literature reviews, comparison of field techniques, and establishment/documentation of QA/QC programs.

A planned outcome of this program is to develop a manual on how to employ the technique for final disposal of reactive tailings underwater. Since the required expertise is not wide spread, the tendering of this project may be difficult, and hence it is proposed that a working group be formed to develop the manual. The group should consist of selected specialized consultants and mining company sponsors.

**Projected Output:**

Water cover should minimize the transport of oxygen, and subsequently limit acid generation.

**Systematic evaluation of existing sites will provide a basis for assessing the overall effectiveness and developing a design criteria manual for underwater disposal techniques.**

Project 2.12.1: Man-made Lakes Disposal Sites - Louvicourt Project
Budget: $350,000
Sponsors: Aur Ressources, Teck, CANMET, Québec
Manager: M. Filion, Teck
Contractor: To be determined

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Objective:

The general objective of the field and laboratory project for the Louvicourt man-made lake tailings basin is to verify the effectiveness of submersion, as a means of preventing oxidation.

Fit with Program:

Disposal of mine wastes in natural bodies of water is sometimes unacceptable to regulatory agencies, and to the public, due to the perceived loss of a biological resource and of general harm to the environment. At many locations, the opportunity exists to develop man-made underwater disposal sites which would attain similar goals with less restrictions than natural lakes.

The Peer Review (Project 2.11.1d) on subaqueous disposal sites concluded that subaqueous disposal of tailings appears to offer physico-chemical advantages over terrestrial disposal, particularly with respect to sulphur oxidation and generation of acid waters. In the same report the scientific review team and MEND noted that the disposal of mine tailings in artificial structures should be more acceptable over disposal in existing lakes. However, few studies have been done in monitoring artificial basins to ensure constant submersion of the mine tailings, and none of the studies conducted on disposal sites in a natural lake environment has had the benefit of earlier data at the start of disposal. The tailings basin monitoring project proposed will conduct field studies to evaluate the effectiveness of submerging tailings as a means of preventing the oxidation of sulphide minerals. Laboratory test work will also be carried out to determine, among others, the optimum depth of water for the cover and oxygen diffusion characteristics.

Projected Output:

Since flooding of mine tailings in artificial basins seems to be the method preferred by new mining operations, the proposed study will lead to a better understanding of the factors involved in operating tailings basins in a man-made lake. Following this work a methods

**manual will be prepared which will identify and discuss the issues that should be considered for the design and construction of the engineered structures to create a man-made lake.**

| | |
|---|---|
| **Project 2.13.2b:** | **Monitoring of the Flooded Solbec-Cupra Tailings Site** |
| **Budget:** | **$150,000** |
| **Sponsors:** | **To be determined** |
| **Manager:** | **L. Bienvenu, Ministère de l'Énergie et des Ressources (MER)** |
| **Contractor:** | **To be determined** |

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**Objective:**

**The objective of this project is to monitor the Solbec-Cupra tailings impoundment during and after flooding. The monitoring program will include surface and groundwater chemistry, hydrology, water balance (e.g. seepage, water depth), meteorological (e.g. precipitation) and wave action (e.g. resuspension of particles).**

**Fit with Program:**

**As distinct from underwater disposal, wet barriers is defined as establishing a water cover on oxidized tailings. As with underwater disposal, further oxidation is considered unlikely but the mobilization of the soluble salts becomes a major consideration. This closure option may be attractive if the fate of these oxidation products can be predicted. The proposed closure plan for the 66 hectare Solbec-Cupra tailings site, with ≈30 to 50% sulphide, is flooding.**

**In Phase (a) of the project (2.13.2a), started in 1989, several fundamental studies using field lysimeters (e.g. water cover only, water cover and limestone) as well as a hydrogeological study of the tailings basin were completed confirming that flooding of the tailings impoundment is possible with natural precipitation and surface runoff over an eighteen-month period. Wave action and microbiological studies together with a synopsis of field lysimeter information were completed in 1993.**

**Cambior, the owner of the site, is planning to flood the site starting in 1994 pending government approval and the procurement of several lots in the vicinity of the tailings basin that will be flooded.**

**Projected Output:**

**A field evaluation report of the flooding close-out option will be prepared. The report will compare field and laboratory results. Such an evaluation will validate the design criteria used for the close-out scenario at the site.**

**Project 2.13.3:** **Flooding of Existing Tailings Sites - Falconbridge**
**Budget:** $170,000
**Sponsors:**..................................................
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..................................................Falconbridge
..................................................$ 155,000
Ontario..................................................$ 15,000
**Manager:** R. Michelutti, Falconbridge
**Contractor:** University of Waterloo

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**Objective:**
The primary objective is to establish the suitability and effectiveness of a water cover on top of sulphidic tailings to prevent acid generation and metal mobilization.

**Fit with Program:**
Studies have been conducted on Falconbridge's 90 hectare "New Tailings" site to evaluate the feasibility and control provided by a shallow water cover on high pyrrhotite (40 to 50%) tailings. The tailings are underlain by low permeability silt and clay deposits, and are covered with low sulphur (1%S), low permeability tailings slimes (0.3 to 2 metres in thickness) to decrease the oxygen and water movement through the tailings prior to flooding. The slime cover has raised the phreatic surface within the tailings, and consequently most of the high sulphide portion is saturated and presently in the unoxidized state. After three years of abandonment, without a water cover, the tailings area has not turned acid.

To date the hydrogeochemistry of the entire site has been extensively evaluated . The water chemistry in the tailings and the gas compositions in the vadose zone indicate that oxidation of pyrrhotite in the tailings is ongoing. The acid generated to date has probably been neutralized by the dissolution of carbonate minerals. Elevated concentrations of ferrous iron represents potential acidity when the water discharges to the surface environment.

Two other sites are also being closely monitored by MEND. All three projects are similar but each have their own peculiarities. For instance the Falconbridge site is for high sulphide tailings containing highly reactive pyrrhotite (40 to 50%), the metal loadings are different in characteristics, the low sulphur cover that has kept the tailings in an unoxidized state and the large groundwater flow component found at this site make this site quite distinct.

A second component of this project is the development of a computer model (WATAIL) to

**assist in the management of water quality associated with disposal of sulphide tailings. The objective of the program is to provide comparisons in loading rates of the major oxidation products to surface water draining from the local watershed in which the tailings basin is contained. The program focuses on rehabilitation strategies based on engineered covers, including underwater scenarios.**

**Projected Output:**
**Performance evaluations from the various flooded sites will be completed, followed by a design criteria manual incorporating standardized laboratory and field data procedures.**

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|---|---|
| Project 2.21.3: | Peer Review of Waite Amulet and Heath Steele Soil Covers |
| Budget: | $50,000 |
| Sponsors: | To be determined |
| Manager: | To be determined |
| Contractors: | Competitive bidding |

Objective:

The objective of this project is to complete a scientific peer review of the design and evaluation of engineered soil covers applied to tailings at Waite Amulet and waste rock at Heath Steele.

Fit with Program:

Natural soil covers are a promising dry barriers for the control of acid generation in sulphide tailings and waste rock. Laboratory test results indicate that the effectiveness of a soil cover is dependent upon the establishment and maintenance of a high degree of saturation within the soil. Composite soil covers have been designed, applied and monitored at the Waite Amulet and Heath Steele sites. Results confirm that the oxygen flux through the cover and the oxidation of sulphide minerals can be substantially reduced in this manner.

A scientific peer review by an independent expert will determine whether any additional experimentation is required prior to the development of protocols for the design, construction and maintenance of engineered soil covers over sulphide tailings and waste rock, to be prepared under a subsequent project (2.21.4). The peer review will ensure the quality and completeness of the field data and interpretations which will provide the basis for the protocols and will enhance the scientific credibility of several key project reports. The review will also assist mine operators and regulators by increasing public confidence in the technical feasibility and cost of engineered soil covers.

Projected Outputs:

The deliverable for this project will be a report which will include a critical review of all project reports and the scientific literature related to soil testing and the design, construction and monitoring of engineered soil covers at the Waite Amulet and Heath Steele sites. The report shall include specific recommendations concerning further research, monitoring or other work which may be necessary to validate the approach or to address any deficiencies which may be identified by the review.

| | |
|---|---|
| **Project 2.21.4:** | **Protocols for Engineered Soil Covers over Tailings and Waste Rock** |
| **Budget:** | **$30,000** |
| **Sponsors:** | **To be determined** |
| **Manager:** | **To be determined** |
| **Contractors:** | **Competitive bidding** |

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**Objective:**

**The objective of this project is to develop protocols for the design, construction and maintenance of engineered soil covers over sulphide tailings and waste rock.**

**Fit with Program:**

**Natural soil covers are a promising dry barrier for the control of acid generation in sulphide tailings and waste rock. Laboratory test results indicate that the effectiveness of a soil cover is dependent upon the establishment and maintenance of a high degree of saturation within the soil. Composite soil covers have been designed, applied and monitored at the Waite Amulet and Heath Steele sites. Results confirm that the oxygen flux through the cover and the oxidation of sulphide minerals can be substantially reduced in this manner.**

**The development of protocols will enable mine operators and regulators to assess the technical feasibility and cost of engineered soil covers on a site specific basis and will provide a sound basis for detailed engineering design and cost estimation, construction supervision and maintenance.**

**Projected Outputs:**

**The deliverables for this project will be a report which will briefly outline the applicability of engineered soil covers and identify critical soil parameters, appropriate reference methods for soil testing, engineering design criteria to be satisfied in the design of robust engineered soil covers over sulphide tailings or waste rock and key performance criteria which may be used for field monitoring of effectiveness. The report will include recommended protocols for soil testing procedures, cover design, construction and maintenance or may refer, where appropriate, to published standards of reference methods adopted by authoritative standards organizations, technical organizations of Canadian jurisdictions.**

**Project 2.23.3:** Porous Envelope Surround Disposal Method - Falconbridge
**Budget:** $123,000 to $190,000 (increase in scope)
**Sponsor:**
Falconbridge
$37,000
Ontario $30,000
**Manager:** M. Wiseman, Falconbridge
**Contractor:** Noranda Technology Centre

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**Objective:**

The objective of this increase in scope for the porous envelope surround disposal method is to complete additional monitoring of the tailings impoundment to ensure a complete feasibility study on the effectiveness of the disposal concept for controlling acid mine drainage.

**Fit with Program:**

Preliminary hydrogeological observations at Falconbridge's Fault Lake tailings site suggest that permeability contrasts between the natural till deposits and the tailings may be sufficient for porous envelope containment to occur. The tailings have been deposited in a kettle lake formed within glacial outwash sand and gravel.

The measurement of hydraulic properties, hydrogeological analyses with numerical modelling and chemical monitoring of appropriate parameters existing on site are ongoing. The 1994 program will include additional boreholes to sample and evaluate the tailings located below the water table. The additional information will be used to verify the 2-D finite element model developed earlier in the study. Further evaluation will be done by seasonal sampling, piezocone resistivity measurements (refer to active Monitoring project 4.6.4), and laboratory analyses to delineate the role of tailings geochemistry.

**Projected Output:**

The effectiveness of the porous envelope surround method will be further evaluated for its effectiveness for controlling acidic drainage. This project will confirm that leaching of the tailings is theoretically reduced to acceptable levels, creating a permanent, cost effective, no maintenance tailings abandonment strategy.

**Project 2.35.2:** Lysimeter Evaluations of Cover Alternatives - Noranda
**Budget:** $195,000 to $275,000 (increase in scope)
**Sponsors:**..........................................................................................................
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.......................................................................................................... Noranda
..........................................................................................................$40,000
**Manager:** L. St-Arnaud, Noranda Technology Centre
**Contractors:** Noranda Technology Centre

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**Objective:**

The objective of this increase in scope is to have a better understanding of the relative effectiveness of different measures in preventing and controlling sulphide oxidation and hence acid generation in waste rock under controlled and field conditions. This follows recommendations made from the review of the milestone report.

**Fit with Program:**

The experiments were started in June 1991 and weekly monitoring of the drainage water from the lysimeters have been taken since. The original scope will be completed in March. The control techniques being investigated are water cover, soil cover, wood bark cover, and addition of limestone and phosphate rock (apatite). Potentially acid-generating waste rock samples used in the investigation were obtained from the Stratmat mine in New Brunswick and from Les Mines Selbaie in Québec. The investigation involved outdoor lysimeter tests and indoor laboratory column experiments.

The first milestone report was evaluated in 1993 and several recommendations were made by the reviewers to complete the project. The increase in scope would include the following objectives:

- Acid-base accounting and paste pH on the weathered rock (post-testing) in indoor and outdoor columns;
- Complete metal analysis of the drainage water and geochemical interpretation;
- Detailed mineralogy on weathered rock: interpretation of the relations between the mineralogy and the quality of the drainage water; and

- **Detailed analysis and explanation of the differences in acid generation between Mines Selbaie and Stratmat waste rock.**

**Projected Output:**

**There are some interesting preliminary results from the monitoring data and the proposed increase will further define the relative effectiveness of the various techniques. In some cases, a comparison of results with other MEND studies will be completed. This report, due in March 1995, will aid in the selection of prevention and control strategies for waste rock disposal.**

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|---|---|
| Project 2.36.1: | In-Pit Disposal - Case Studies |
| Budget: | $50,000 |
| Sponsors: | HBM&S |
| Manager: | To be determined |
| Contractor: | Competitive bidding |

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Objectives:

The objective of this project is to complete a case study review on the use of mined out pits as a depository for potentially acid generating materials, especially waste rock.

Fit with Program:

Covering waste rock and tailings sites with water has been shown to minimize the transport of oxygen and limit or even totally prevent acid generation. The placement of oxidized waste rock or tailings into a pit, from which it was excavated, beneath a water cover is expected to have similar results. However, the fate of soluble salts is currently unresolved.

MEND committee members have identified several cases where in-pit disposal has been utilized for the disposal of acidic tailings and waste rock (e.g. Equity Silver, Bell, Owl Creek, Solbec) and others where in-pit disposal is being considered as a close-out option (e.g. Stratmat). The particulars involved in each of the scenarios would be useful information for operators contemplating a similar disposal technique as part of their waste management philosophy.

What is envisaged in this project is a review of all scenarios identified in Canada, U.S.A. and other parts of the world where in-pit disposal of acidic waste has been conducted or was evaluated. Each case would be reviewed and specific details would be collected. Some of the more important data to be collected, to name a few, could include:

- hydrology of the pit;
- characterization of the material;
- neutralizing agents added;
- volume of material placed in pit;
- cover applied; and
- monitoring program.

**Projected Output:**

This type of information if collected on all known sites would be a very useful reference document for those in the mining industry contemplating the placement of waste in mined out pits.

**Project 2.36.2:** In-pit Underwater Disposal of Oxidized Waste Rock
**Budget:** $166,000
**Sponsors:** ........................................................................ Heath Steele Mines ........................................................................$ 34,000
Noranda ..................................................................................$132,000
**Manager:** M. Patterson, Heath Steele Mines
**Contractor:** Heath Steele Mines

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Objective:

The objective of this project are to evaluate the effectiveness and operating costs to place oxidized waste rock in a flooded open pit, treat pit water by lime neutralization and cover exposed mineralization in the pit walls.

Fit with Program:

Acid generation results from the bacterially catalyzed oxidation of sulphide minerals. Acid generation may be prevented by excluding oxygen and/or water. Results to date indicate that subaqueous disposal of unoxidized sulphide wastes prevents acid generation by controlling oxygen transport.

Waste rock is commonly stockpiled near open pit mines and acid generation has occurred in waste rock stockpiles at a number of sites. Disposal of oxidized waste rock in a flooded open pit is a potential long term control option, but could potentially result in the mobilization of soluble oxidation products. An assessment of the technical and economic feasibility of backfilling a flooded open pit with oxidized material must therefore consider the long term evolution of surface and groundwater quality and requirements for active treatment prior to abandonment.

This project would include laboratory evaluation of contaminant leaching and water treatment requirements, prediction of surface and groundwater quality and a large scale field trial using the N5 open pit. The site is well suited for such a trial as baseline hydrogeochemical data is available and waste rock was removed to stockpiles near the Stratmat open pit. The methodology developed would enable mine operators and regulators to assess the site specific feasibility of an attractive control option for addressing inventories of oxidized waste rock at a number of other sites.

**Projected Outputs:**

**The deliverables from this project will include detailed reports of the laboratory evaluation and field trials. The final report will include a comparison of predicted and actual water quality, water treatment requirements and costs.**

Project 2.45.2: Separation of Sulphides from Mill Tailings - Case Studies
Budget: $50,000
Sponsors: To be determined
Manager: To be determined
Contractors: Competitive bidding

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### Objective:

The objective of this project is to complete a case study review on the use of separation of sulphides as a method to control acid mine drainage.

### Fit with Program:

The acid generation in tailings is enhanced by bacterial activity. Most of the acid drainage work to date in MEND has looked at the elimination of water and/or oxygen from the tailings, both of which are required to oxidize the sulphides. This project will look at case studies where sulphide tailings were separated into their non-sulphide and sulphide fractions.

Improved understanding of the feasibility of separating sulphides will be gained by reviewing case studies. MEND committee members have identified several cases where the separation of sulphides has been tried (e.g. INCO, HopeBrook, Snip, Norebec-Manitou, Rio Algom, Denison). Several mines have also mentioned the separation of sulphides as a possible close-out option since the non-sulphide portion could be used as a cover on top of the acid generating material.

Each case would be reviewed and specific details would be collected. Some of the more important data to be collected would be a description of the material (e.g. % sulphides before and after, quantities), a description of what was done (e.g. separation technique used and the results) and what was done with the products (e.g. disposal options - underground placement and/or dam building).

### Projected Output:

Pre-separation as a method to control AMD is a Priority I area in the MEND Revised Research Plan. If the sulphides can be separated from the non-sulphides, this opens up several disposal options. Since the sulphide portion will have a significantly reduced volume, separate

**underwater disposal in a lined containment may become realistic.**

**Information on all known sites where separation of sulphides was attempted would be a very useful reference document for those in the mining industry contemplating sulphide separation.**

**Project 3.14.1:** **Evaluation of Passive Systems for Treatment of AMD**
**Budget:** **$60,000**
**Sponsors:**
**CANMET**
**$60,000**
**Manager:** **Geneviève Béchard, CANMET**
**Contractor:** **Competitive bidding**

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**Objectives:**

**This project will complete a review and evaluation of passive treatment systems, identify the critical design criteria and operating parameters, provide an estimate of costs for treatment of AMD using passive systems and make recommendation on their applicability in Canada.**

**Fit With Program:**

**Originally, MEND considered passive treatment systems, particularly those methods using biotechnology, as practical and economical alternatives to lime treatment. Considerable research and process development has been done on passive systems for treatment of AMD. In Canada, through the MEND Program, a considerable amount of resources has been allocated to projects related to passive treatment options.**

**These studies have demonstrated that the use of passive systems to treat acidic seepages is technically feasible but the performance and the applicability of these systems remain uncertain. Several process-limiting factors, such as temperature, flow rates, and rates of addition of bacteria nutrients, were identified during these studies. In order to assess the performance and applicability of passive systems, MEND has decided to conduct an evaluation of passive treatment systems, based on the scientific knowledge and state-of-the-art provided by these studies.**

**Projected Outputs:**

**The deliverables will include:**

- **An evaluation of passive treatment systems that were investigated by MEND and in er studies in the U.S. and around the world;**

- **An analysis of capital and operating costs required for the passive treatment of D; and**

- **The identification of conditions of application and recommendation on applicability assive treatment systems in Canada.**

| | |
|---|---|
| **Project 3.21.3:** | **Removal of Metals from AMD - Pilot Tests** |
| **Budget:** | **$125,000** |
| **Sponsors:** | **To be determined** |
| **Manager:** | **To be determined** |
| **Contractor:** | **Competitive bidding** |

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**Objectives:**

**This project will result in the demonstration on a small pilot scale of the applicability of ion exchange for removal of selected metals from acidic drainage. The metals removal process will significantly lower the metal content of treatment sludges.**

**Fit With Program:**

**Removal of metals from acidic drainage effluents would allow treatment plant operators to generate treatment products which may not pose, in the long term, the risk of generating a toxic effluent. This might provide the walk-away closure scenario when acidic drainage is effectively stopped, and the lime treatment is shut off. Little to no care and maintenance of treatment sludge ponds would be required if the sludge has low heavy metal content. "Walk-away" at minimum cost is the property owner's prime closure objective.**

**Two projects were conducted on the removal of metals from acidic drainage before lime neutralization. The first one was bench scale tests on selective precipitation which was completed in 1993 (3.21.2a); and the second was bench scale tests on ion exchange which will be completed in 1994 (3.21.1b).**

**As outlined in the Revised Research Plan, either the ion exchange or the selective precipitation method would be tested on a small pilot scale based on the recommendations in the laboratory-scale studies.**

**The study on selective precipitation was carefully reviewed and, based on economics and range of applicability, it is not recommended for a pilot study. The ion exchange study will also be reviewed after completion. If the decision is negative with respect to continuing the project for pilot scale tests, the budget resources could be switched to sludge and treatment products stabilization.**

**Projected Outputs:**

**This project will result in description and recommendations of the design and operation of a ion exchange process to remove metals from acid mine drainage. Actual commercialization of the process will cost much more and will be done outside of MEND.**

**Project 3.41.1a:** In Situ Treatment of AMD
**Budget:** $41,000
**Sponsor:** ..........................................................................................................
..........................................................................................................................
...........................................................................................................Falconbridge
.................................................................................................................$11,000
MOE..............................................................................................$30,000
**Expenditures:** $0
**Manager:** D. Abbott, MOEE
**Contractor:** David Blowes, University of Waterloo

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**Objectives:**

To develop and test the use of porous reactive walls for the subsurface treatment of drainage waters derived from sulphide-bearing mine-tailings impoundments and to demonstrate the use of this technology on a field scale.

**Fit With Program:**

The proposed research program directly addresses MEND's goal to mitigate acid production from mining sites and to prevent damage to large areas of the aquatic and terrestrial environment.

The need for new, more affordable, technologies for the remediation of environmental problems continues. It is anticipated that the results of the proposed research will lead to the development of marketable groundwater remediation programs that can be taken to market shortly after the effectiveness of the approach has been demonstrated.

**Projected Outputs:**

The first year of this study (phase I) will see the theoretical and laboratory assessment of reactive mixtures potentially suitable for treatment of drainage waters associated with inactive mines wastes. A variety of reactive materials will be studied. Selection of an optimum material for field testing will be done in the second year along with development of fundamental characteristics, porosity, permeability required for solute-transport modelling.

A go/no go decision to continue the project will be taken after a technical review of phase I.

**Phase II will include field testing of porous reactive walls at an isolated field site to assess the effectiveness of this remediation technique at the field scale continued laboratory testing and evaluation.**

| | |
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| **Project 4.6.1b:** | **Geophysical Monitoring Techniques - Further Application and Development** |
| **Budget:** | **$100,000** |

**Sponsor:** ..................................................................................................................
..................................................................................................................................
..................................................................................................................**CANMET**
..................................................................................................................**$50,000**
**Ontario** ..................................................................................................**$50,000**

| | |
|---|---|
| **Manager:** | **To be determined** |
| **Contractor:** | **Competitive bidding** |

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**Objective:**

**To further develop and apply the use of electrical and electromagnetic geophysical methods at an AMD site as a means of monitoring the presence and transport of acidic mine drainage in an effective and economic manner.**

**Fit With Program:**

**Geophysical methods determine variations in physical properties through the measurement of various fields and waves including gravitational, electromagnetic, acoustic etc., which penetrate the earth. These measurements provide information on variations in the physical properties of the subsurface while being non-intrusive. The depth of penetration is limited only by the power and sensitivity of the measuring system and/or the size of the source, although resolution decreases with depth of penetration.**

**Geophysical methods have been used for many years by the mining sector worldwide for exploration. The basic techniques have been adapted over the years and the associated expertise and instrumentation has to a large extent been developed in Canada. Only recently has this expertise been applied to acid mine drainage identification and tracking. Based on a review of selected geophysical techniques, the report from Project 4.6.1 outlines a recommended sequence for the use of electrical and electromagnetic geophysical methods for AMD site investigations. The recommendations outlined in this report will be used in developing the terms of reference for further application and development of these techniques.**

**Projected Outputs:**

Geophysical interpretations in general do not currently provide the detail required for a complete environmental or geotechnical investigation. They can however give a relatively rapid and inexpensive reconnaissance of the subsurface if properly applied. This information can then be used for example to target subsequent drilling or to interpret subsurface conditions away from or between drill holes. The development of application methodologies and the enhancement of data interpretation are required to optimize the use of these techniques in the rapid and cost effective monitoring of acid mine drainage sites.

RECOMMENDEDTECHNOLOGY TRANSFER
March 1994

**Project 5.2.1d:** Communications Plan - Video on AMD/MEND
**Budget:** $150,000
**Sponsors:**
CANMET
$75,000
**Manager:**
Ontario
$75,000
**Contractor:** Competitive bidding

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Objectives:

The objective of this project is to put in place a mechanism to inform key audiences about the issue of acidic drainage and the new affordable technologies being developed to solve the problem; and to transfer information to technical people having to deal with acid mine drainage.

Fit with Program:

The actual message on acid mine drainage being carried by media and various organizations to the general public is that AMD is a major environmental problem mainly caused by poor practices of the mining industry. Bad images are being shown but little is said on what causes the problem and what is being done to solve it. To ensure that the information is clearly understood by technical people and the general public, including politicians and funders, a Task Force was appointed by the Board of Directors in 1992, to implement a Communications plan.

In June 1993, a workshop was held to identify MEND business strategies, targeted audiences, communications strategies and communications vehicles. Priorities were set in terms of primary audiences and an agreement was reached on an action plan. To address the targeted audiences less intimately involved with AMD, some communications vehicles were recommended.

The key audiences identified are technical people at mine sites, consultant companies, universities, etc., interested in getting more information on the technology being developed by

MEND, and the general public, including politicians and funders, interested in knowing more of what AMD is and what MEND is doing to solve the problem.

**Projected Outputs:**

The video would provide information on what acid mine drainage is, what MEND is and how MEND is solving the problem. Because two audiences have been identified, the video would be in two parts: a longer, more technical version to transfer information to technical people; and a shorter, more general version to inform the general public, including politicians and funders. Both versions will be prepared in English and French.

**Project 5.4.2:** AMD Handbook
**Budget:** $150,000
**Sponsors:**........................................................................................................
..............................................................................................................................
..............................................................................................................CANMET
..............................................................................................................$75,000
**Manager:**..........................................................................................................
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..............................................................................................................Ontario
..............................................................................................................$75,000
**Contractor:** Competitive bidding

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**Objectives:**

The "AMD Handbook" will provide, in a single document, a comprehensive summary of all key information on MEND investigations and AMD work by others.

**Fit With Program:**

As stated in the Revised Research Plan, the work of the Technology Transfer committee compliments the activities of the technical committees in getting the results of the research work to the users. The committee ensures that the information is clearly understood, particularly for newly developed technology. Poorly implemented technology could easily be very counterproductive for MEND, and would result in lost opportunities to reduce the cost of dealing with acidic drainage.

A single source of information on AMD and MEND's research, complimentary to the many detailed technical reports, would be a beneficial references for users. The users would save a lot of time and efforts by not having to look up several sources to get relevant information.

**Projected Outputs:**

The manual will provide information on engineering, economic and scientific tables for mine and mill operators, engineering design and environmental staff, consulting engineers, universities and government.

The preparation of the handbook would be done in collaboration with MEND technical

**committees and other individuals and organizations who could review material for accuracy, adequacy and pertinence. The chapters would be updated on a progressive basis and the integration of all chapters would be done towards the end of the MEND program.**

**March 1994**

| | |
|---|---|
| **Project 5.6.3** | **Fourth International Conference on the Abatement of Acidic Drainage** |
| **Budget:** | **To be determined** |
| **Sponsors:** | **To be determined** |
| **Manager:** | **George Poling, UBC** |

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**Objective:**

**This project will provide the basis for the planning and hosting of the Fourth International Conference on Abatement of Acidic Drainage in Vancouver 1997.**

**Fit with Program:**

**Like the previous International Conferences in Montréal and the 1994 conference in Pittsburgh, participation in this Conference is an excellent way to present and discuss the latest technical developments in dealing with acidic drainage. Hence, it fits with the priorities for Technology Transfer as defined in the Revised Research Plan.**

**Projected Outputs:**

**This conference is a good opportunity for MEND members to exchange new information with others working in the field of acidic drainage. This conference will provide a Peer Review of the MEND developed technology.**

| | | |
|---|---|---|
| **Project 6.2:** | **New Ideas Solicitation - Round 2** | |
| **Budget:** | **$120,000** | |
| **Sponsors:** | | |
| | | |
| | | **CANMET** |
| | | **$15,000** |
| | **Québec** | **$20,000** |
| | **Noranda** | **$55,000** |
| | **Environment Canada** | **$10,000** |
| | **Ontario** | **$20,000** |
| **Facilitator:** | **K. Wheeland** | |
| **Contractors:** | **Various** | |

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**Objectives:**

**The New Ideas Task Force is soliciting and developing new ideas and innovation that will provide technology to significantly reduce the cost of preventing, controlling and treating acid mine drainage. A second round of solicitation is aimed at a broader group of contractors, as opposed to a university focus**

**Fit With Program:**

**The Revised Research Plan of 1992, approved by the MEND Board in August 1992, required that about 15% of the remaining expenditures be allocated to soliciting and funding new ideas and innovation. The resulting technology would be:**

- **inexpensive to implement and maintain and be long-lasting;**
- **broadly applicable across Canada;**
- **different from current known methods of preventing and controlling acidic drainage; and/or**
- **result in very significant reduction in the cost of application of known technology.**

**The New Ideas Task Force was set up to solicit, evaluate, fund (up to $10,000) and manage those proposals selected. The first round of solicitation (6.1.1) provided a number of promising technologies. It also introduced the subject of AMD to a wide spectrum of researchers and entrepreneurs, many of which will continue to participate.**

**In late 1993, the New Ideas Task Force initiated a second solicitation through extensive advertising in the MEND Newsletter, CIMM bulletin and by doing presentations at several locations across Canada. By the end of the year, 58 proposals had been received and an initial evaluation showed that 7 proposals had merit for closer consideration. Nine proposals were referred to technical committees. It is recommended that up to 13 projects be funded in 1994, for an expenditure of $120,000.**

# APPENDIX F
## MEND Reports Available
## Rapports Disponibles sur NEDEM

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### PREDICTION/PRÉVISION

1.11.1 Critical Literature review of Acid Drainage from Waste Rock, April 1991. $25

1.14.2 Diversité microbiologique dans la production de drainage minier acide à la halde sud de la Mine Doyon, March 1994. $30

Development of a Modified MPN Procedure to Enumerate Iron Oxidizing Bacteria, March 1994. $20

Heat Transfer During Acid Mine Drainage Production in a Waste Rock Dump, La Mine Doyon (Québec), March 1994. $25

Monitoring of Acid Mine Drainage: Chemical Data from La Mine Doyon-South Waste Rock Dump, March 1994. $25

Water Budget for the Waste Rock Dump at "La Mine Doyon" Québec, March 1994. $30

Mineralogical Transformations Associated with AMD Production in a Waste Rock Dump - La Mine Doyon-South Waste Rock Dump. March 1994. $20

1.16.1a Investigation of Prediction Techniques for Acid Mine Drainage, November 1989. $25

1.16.1b Acid Rock Drainage Prediction Manual, March 1991. $40

1.16.1c New Methods for Determination of Key Mineral Species in Acid Generation Prediction by Acid-Base Accounting, April 1991. $25

1.17.1a Hydrogeochemical Investigation of Reactive Tailings at the Waite Amulet Tailings Site, Noranda, Québec - 1985 Program, July 1986. $25

1.17.1b Hydrogeochemical Investigation of Reactive Tailings at the Waite Amulet Tailings Site, Noranda, Québec, Phase 2 - 1986 Program, July 1987. $25

1.17.1c Hydrogeochemical Investigation of Reactive Tailings at the Waite Amulet Tailings Site, Noranda, Québec, Phase 3 - 1987 Program, Volume I Report, May 1988. $25

Hydrogeochemical Investigation of Reactive Tailings at the Waite Amulet Tailings Site, Noranda, Québec, Phase 3 - 1987 Program, Volume II - Appendices, March 1988. $25

Hydrogeochemical Investigation of Reactive Tailings at the Waite Amulet Tailings Site, Noranda,

| | |
|---|---|
| | Québec, Phase 3 - 1987 Program, Supplementary Report, March 1989. $25 |
| 1.17.1d | Hydrogeochemical Investigation of Reactive Tailings at the Waite Amulet Tailings Site, Noranda, Québec, "Generation and Evolution of Acidic Pore Waters at the Waite Amulet Tailings - Final Report", April 1990. $60 |
| 1.21.1a | Critical Review of the Reactive Acid Tailings Assessment Program (RATAP.BMT2), April 1990. $30 |
| 1.21.1b | Workshop on Modelling of Reactive Tailings Sponsored by the MEND Prediction Committee, Final Report, August 1990. $40 |
| 1.22.1a | Field Procedures Manual: Gas Transfer Measurements Waste Rock Piles Heath Steele Mines New Brunswick, March 1994. $30 |
| 1.32.1 | Prediction and Prevention of Acid Rock Drainage from a Geological and Mineralogical Perspective, October 1993. $35 |

## PREVENTION AND CONTROL/PRÉVENTION ET CONTROLE

| | |
|---|---|
| 2.11.1a | Subaqueous Disposal of Reactive Mine Wastes: An Overview, June 1989. $25 |
| | A Preliminary Assessment of Subaqueous Tailings Disposal in Benson Lake, British Columbia, March 1990. $25 |
| | A Preliminary Assessment of Subaqueous Tailings Disposal in Anderson Lake, Manitoba, March 1990. $25 |
| | A Preliminary Assessment of Subaqueous Tailings Disposal in Mandy Lake, Manitoba, March 1990. $25 |
| | Geochemical Assessment of Subaqueous Tailings Disposal in Buttle Lake, British Columbia, March 1990. $25 |
| 2.11.1b | Geochemical Assessment of Subaqueous Tailings Disposal in Anderson Lake, Snow Lake Area, Manitoba, September 1990. $25 |
| | Geochemical Assessment of Subaqueous Tailings Disposal in Mandy Lake, Flin Flon Area, Manitoba, September 1990. $25 |
| 2.11.1c | A Preliminary Biological and Geological Assessment of Subaqueous Tailings Disposal in Benson Lake, British Columbia, March 1991. $25 |
| | Chemical Diagenesis of Submerged Mine Tailings in Benson Lake and Natural Sediments in Keogh Lake, Vancouver Island, British Columbia, June 1992. $25 |

| | |
|---|---|
| 2.11.1d | A Critical Review of MEND Studies Conducted to 1991 on Subaqueous Disposal of Tailings, July 1992. $25 |
| 2.11.2a | Literature Review Report: Possible Means of Evaluating the Biological Effects of Sub-Aqueous Disposal of Mine Tailings, March 1993. $25 |
| 2.20.1 | Evaluation of Alternate Dry Covers for the Inhibition of Acid Mine Drainage from Tailings. March 1994. $30 |
| 2.21.1 | Development of Laboratory Methodologies for Evaluating the Effectiveness of Reactive Tailings Covers (includes diskette), March 1992. $40 |
| 2.23.2ab | Hydrologic and Hydrogeologic Evaluation of the Thickened Tailings Disposal System at Kidd Creek Division, Falconbridge Limited, October 1993. $35 |
| 2.24.1 | Manual of Methods Used in the Revegetation of Reactive Sulphide Tailings Basins, November 1989. $20 |
| 2.25.1a | Reclamation of Sulphide Tailings Using Municipal Solid Waste Compost: Literature Review and Recommendations, July 1992. $25 |
| 2.31.1a | Health Steele Waste Rock Study, Phases 1 to 3, March 1992. $40 |
| 2.35.2 | Evaluation of Techniques for Preventing Acidic Rock Drainage: First Milestone Research Report, October 1993. $35 |
| 2.44.1 | Microbial Plugging of Uranium Mine Tailings to Prevent Acid Mine Drainage - Final Report, December 1992. $25 |

## TREATMENT/TRAITEMENT

| | |
|---|---|
| 3.11.1 | Treatment of Acidic Seepages Using Wetland Ecology and Microbiology: Overall Program Assessment, July 1993. $35 |
| 3.12.1a | Assessment of Existing Natural Wetlands Affected by low pH, Metal Contaminated Seepages (Acid Mine Drainage), May 1990. $25 |
| 3.12.2 | Panel Wetlands - A Case History of Partially Submerged Pyritic Uranium Tailings Under Water. February 1993. $35 |
| 3.21.1a | Study on Metals Recovery/Recycling from Acid Mine Drainage, July 1991. $25 |

## MONITORING/SURVEILLANCE

| | |
|---|---|
| 4.1.1 | Field Sampling Manual for Reactive Sulphide Tailings, November 1989. $15 |

4.2.1 Review of Canadian and United States Legislation Relevant to Decommissioning Acid Mine Drainage Sites, September 1993. $25

4.3.1 RTS-1, RTS-2, RTS-3 and RTS-4: Sulphide Ore Mill Tailings Reference Materials, April 1990. $25

4.8.2 Evaluation of an Underwater Monitoring Probe for Locating and Estimating the Impact of Groundwater Discharges to Surface Waters Adjacent to Potential Sources of Acid Mine Drainage (Northern Ontario Development Agreement), March 1994. $30

## TECHNOLOGY TRANSFER/TRANSFERT DE LA TECHNOLOGIE

5.5.1 Reactive Acid Tailings Stabilization (RATS) Research Plan, July 1988. $15

5.6.1 Proceedings - Second International Conference on the Abatement of Acidic Drainage, Montréal, September 16, 17 and 18, 1991. (4 Volumes) $150
(Contact MEND Secretariat to obtain - tel: 613-995-4681 fax: 613-996-9673)

5.7.1 1992 Revised Research Plan/Plan de recherche revisé 1992, August 1992. Complimentary

### NEW IDEAS/NOUVELLES IDÉES

6.1 Preventing AMD by Disposing of Reactive Tailings in Permafrost, December 1993. $25.

6.2 Polymer-Modified Clay as Impermeable Barriers for Acid Mining Tailings, April 1994. $25.

6.3 A Critique of Japanese Acid Mine Drainage Technology. April 1994. $35. 04/9

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# Reports Published Through the British Columbia Acid Mine Drainage Task Force

## PREDICTION/PRÉVISION

1.15.1 Acid Drainage from Mine Walls: The Main Zone Pit Equity Silver. 1990. $40

## PREVENTION AND CONTROL/PRÉVENTION ET CONTROLE

**2.11.1c A Preliminary Biological and Geological Assessment of Subaqueous Tailings Disposal in Benson Lake, British Columbia. 1991. $30**

**Chemical Diagenesis of Submerged Mine Tailings in Benson Lake and Natural Sediments in Keogh Lake, Vancouver, British Columbia. 1992. $30**

**2.23.1 Draft Acid Rock Drainage Technical Guide - Volume I, August 1989. $56**

**2.32.1 Kutcho Creek Project Acid Generation Testwork: Blending and Segregation. Final Report. 1992. $45**

**Kutcho Creek Project Acid Generation Testwork: Phase II. 1990. $40**

## MONITORING/SURVEILLANCE

4.5.2 Field QA/QC Protocols for Monitoring and Predicting Impacts of Acid Rock Drainage, 1992. $30

4.7.1 Monitoring Acid Mine Drainage prepared for B.C. Acid Mine Drainage Task Force, August 1990. $36

4.7.2 Literature Review for Biological Monitoring of Heavy Metals in Aquatic Environments, September 1990. $40

4.7.3a The Effect of Treated Acid Mine Drainage on Stream Macroinvertebrates and Periphytic Algae: An In-Situ Mesocosm Experiment, September 1990. $27

4.7.3b Stream Community Responses to a Gradient of Acid Mine Drainage. 1992. $30

4.7.4 Review of Sediment Monitoring Techniques prepared for B.C. Acid Mine Drainage Task Force, November 1990. $36

4.7.5 Ion Speciation Model (with diskette), 1992. $45

4.7.6 Use of Paleolimnological Techniques to Assess the Effects of Acid Rock Drainage in British Columbia, 1992. $30

## Other Reports Available Through the British Columbia Acid Mine Drainage Task Force

Acid Mine Drainage - Designing for Closure, May 1990. $111

Hydrogeological Assessment and Development of AMD Control Technology for Myra Falls Waste Rock, September 1990. $40

Investigation & Design of Mine Dumps Interim Guidelines, May 1991. $69

Kutcho Creek Project Acid Generation Testwork Phase II, September 1990. $40

Literature Review on In-Situ Treatment of Acidic Rock Dumps with Lime or Lime/Phosphate, 1992. $20

Operation & Monitoring of Mine Dumps Interim Report, May 1991. $69

Shotcrete Application of Cementitious Sealant Materials for Acid Rock Drainage Control Prepared for B.C. Acid Mine Drainage Task Force, April 1991. $36

Survey of Closed and Abandoned Mines in B.C. for Acid Mine Drainage, 1992. $50

Use of Zeolite to Treat Acid Rock Drainage from Britannia Mine, 1992. $20

15th Mine Reclamation Symposium: Reclamation and Sustainable Development. Kamloops, British Columbia. June 1991. $76

17th Mine reclamation Symposium: Building Confidence. Port Hardy, British Columbia. 1993. $57

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